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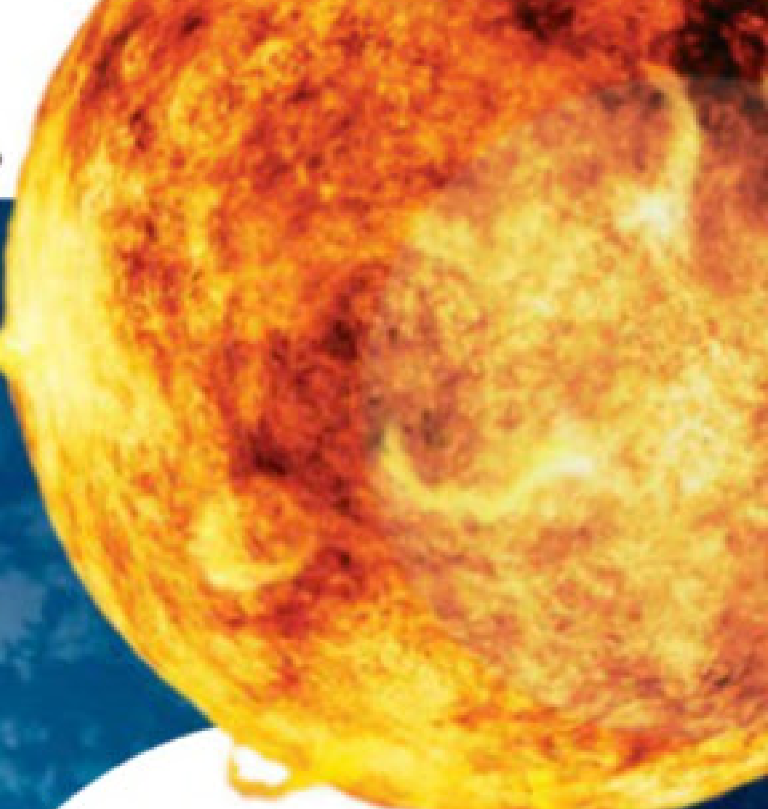

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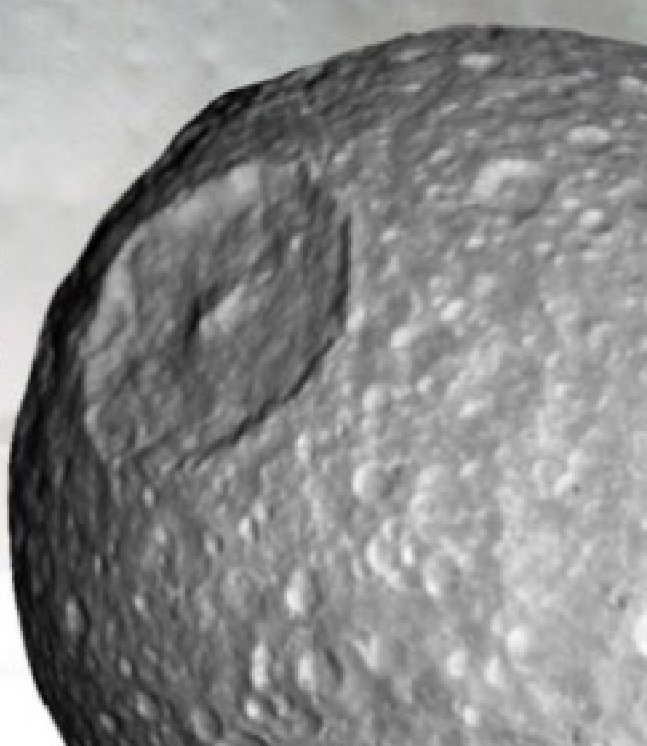

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Discover the wonders of the universe

It won't be long until the opportunity to become an astronaut, of a kind, is within the reach of everyone. Commercial space flight is really taking off (pun intended) across the Western world, including the UK, which may well have its own commercial space port by 2018, based in Lossiemouth, Scotland. At the moment space tourism is the preserve of the fortunate minority who can afford a ticket, the cost of which can run into hundreds of thousands of pounds Sterling.

If we look to the modern aviation industry as an analogue, the cost of jumping on a plane that scrapes the edge of Earth's atmosphere should decrease dramatically in the next few decades: the price of a Trans World Airlines ticket from New York to Paris in 1955 was $310 – a tenth of the national average US salary at the time!

A trip into space will soon be a realistic goal on everyone's bucket list. Even if you've never fantasised about stepping out of the airlock and floating around in microgravity, the process of going from school into space must have piqued your curiosity at some point.

> "In those 22 orbits we'll get some unique science, science that we can't currently do"
> **Linda Spilker, Cassini project scientist**

We've included some of our favourite cosmic subjects in this issue of **All About Space**: black holes are an endless source of fascination for us, so we want to show you Cygnus X-1, the strange and powerful astronomical anomaly a cosmic step away from our own Solar System.

Also, seeing as the Northern Hemisphere is now basking in a long summer daytime, we've provided a beginner's guide to safely observing our nearest star, the Sun, using your telescope. Enjoy the issue!

Ben Biggs
Editor

Crew roster

David Crookes

■ Dave shows us how anyone can get a job in the space industry (hint: being really brainy helps a lot)

Gemma Lavender

■ She's currently being deprived of night skies, but that hasn't stopped Gemma watching the Sun

Luis Villazon

■ Luis follows up last issue's opening gambit, with part two of the Quest to Conquer Space

Giles Sparrow

■ Strange space phenomena like the black hole, Cygnus X-1, is a bit of a pet subject for Giles

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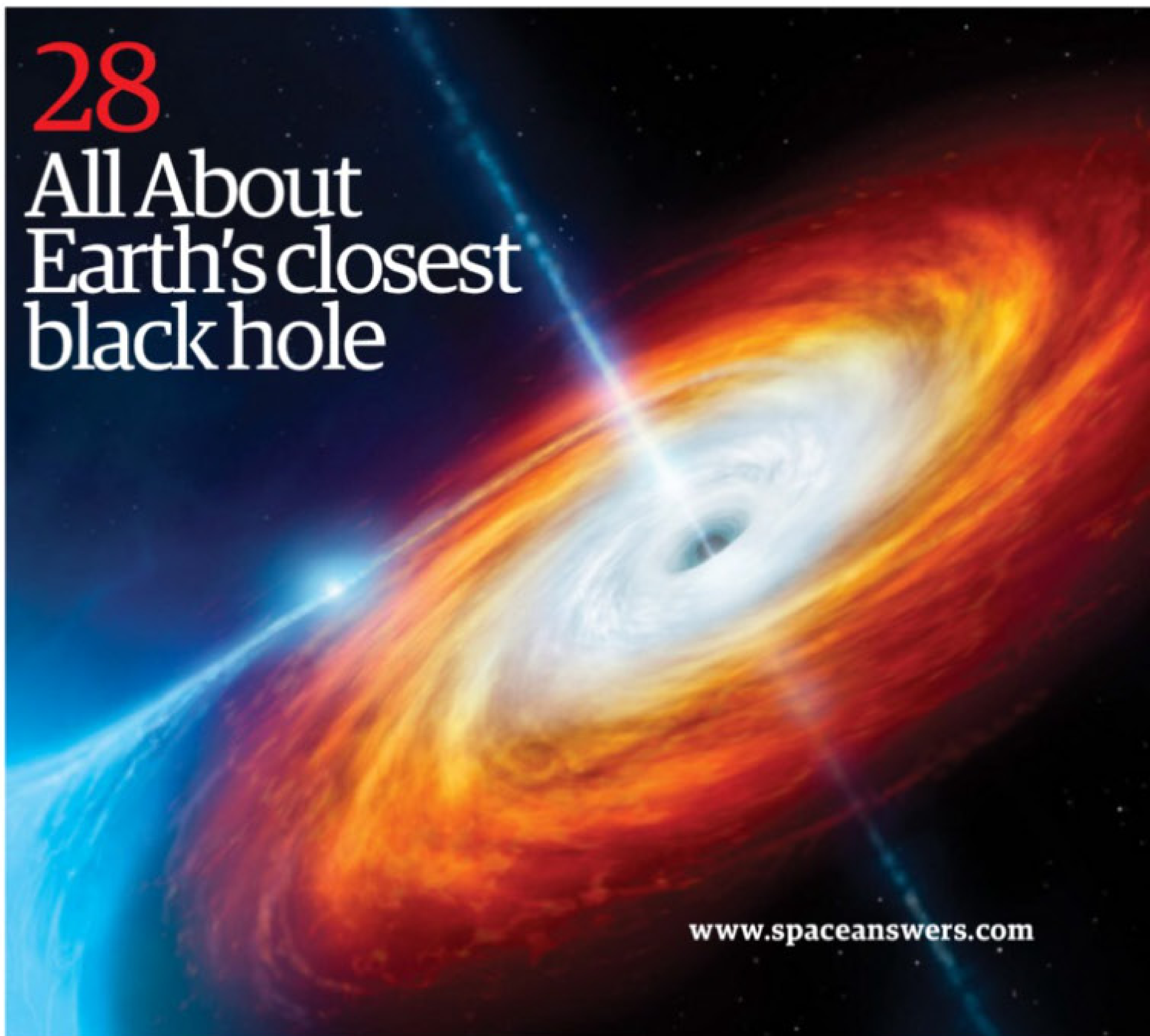

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> “Maybe the lakes will evaporate, maybe clouds will form and it will rain, there could be dry lake beds…”

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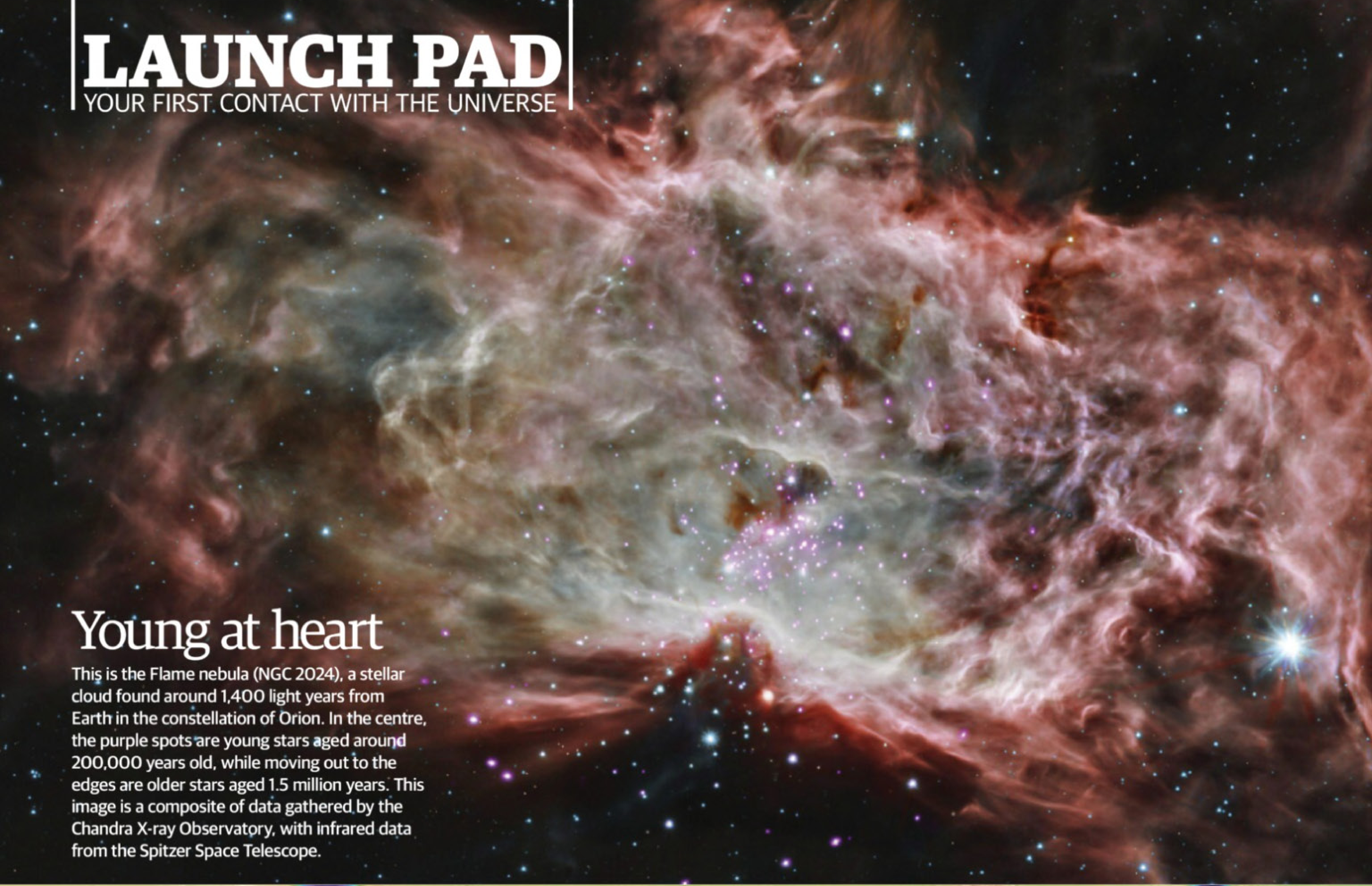
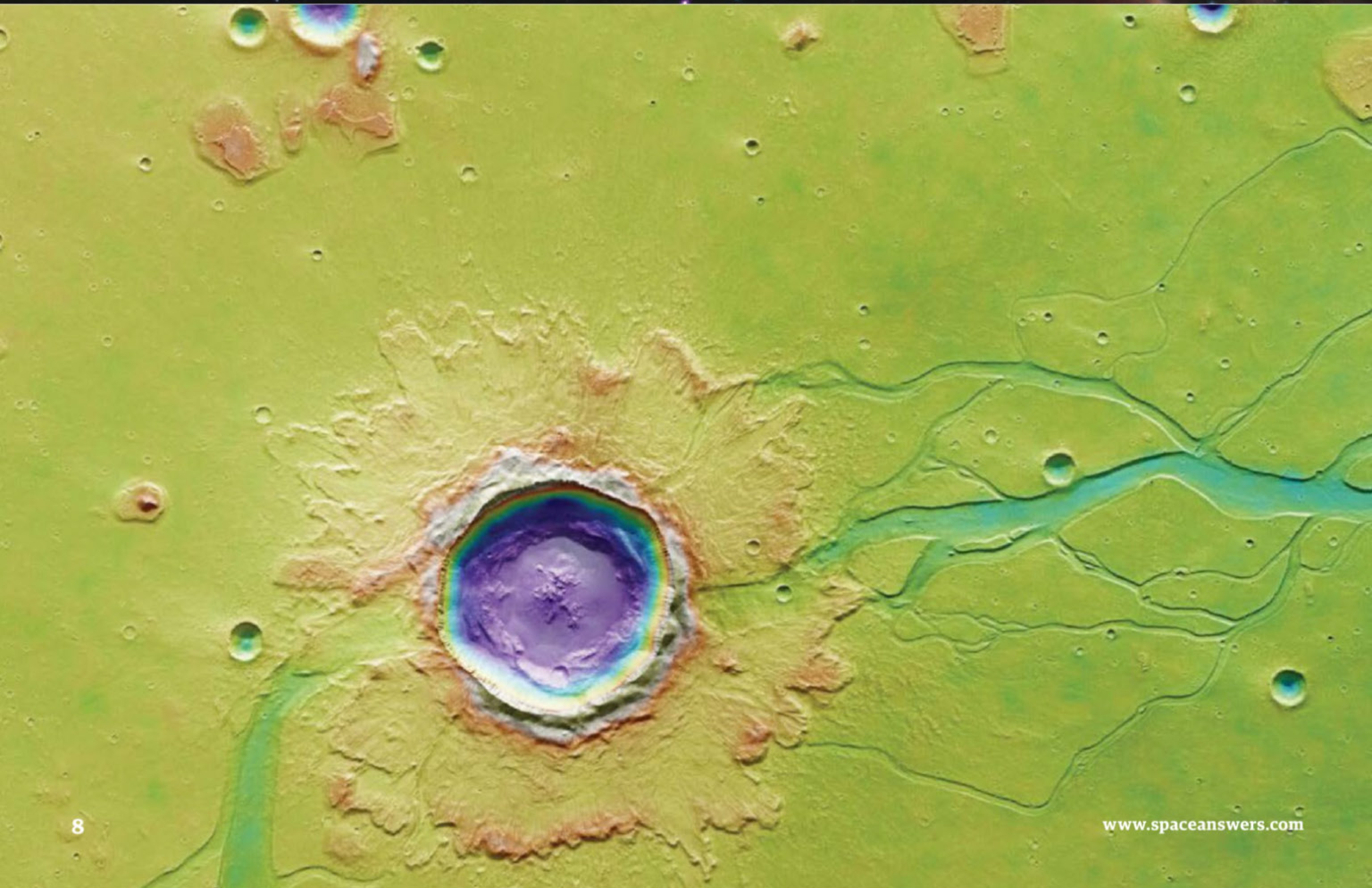
Lucky streak

The site of ALMA's 66-strong array of antennae in the Atacama Desert provides an invariably epic night-sky vista, even for the naked-eye astronomer. However, the fleeting presence of the meteor fireball streaking across the sky in the lower left of this image is a far rarer sight and a perfectly timed photograph of the event is more seldom still. It was captured by the ESO's photo ambassadors on their 17-day tour across three observing sites in the Chilean Andes.



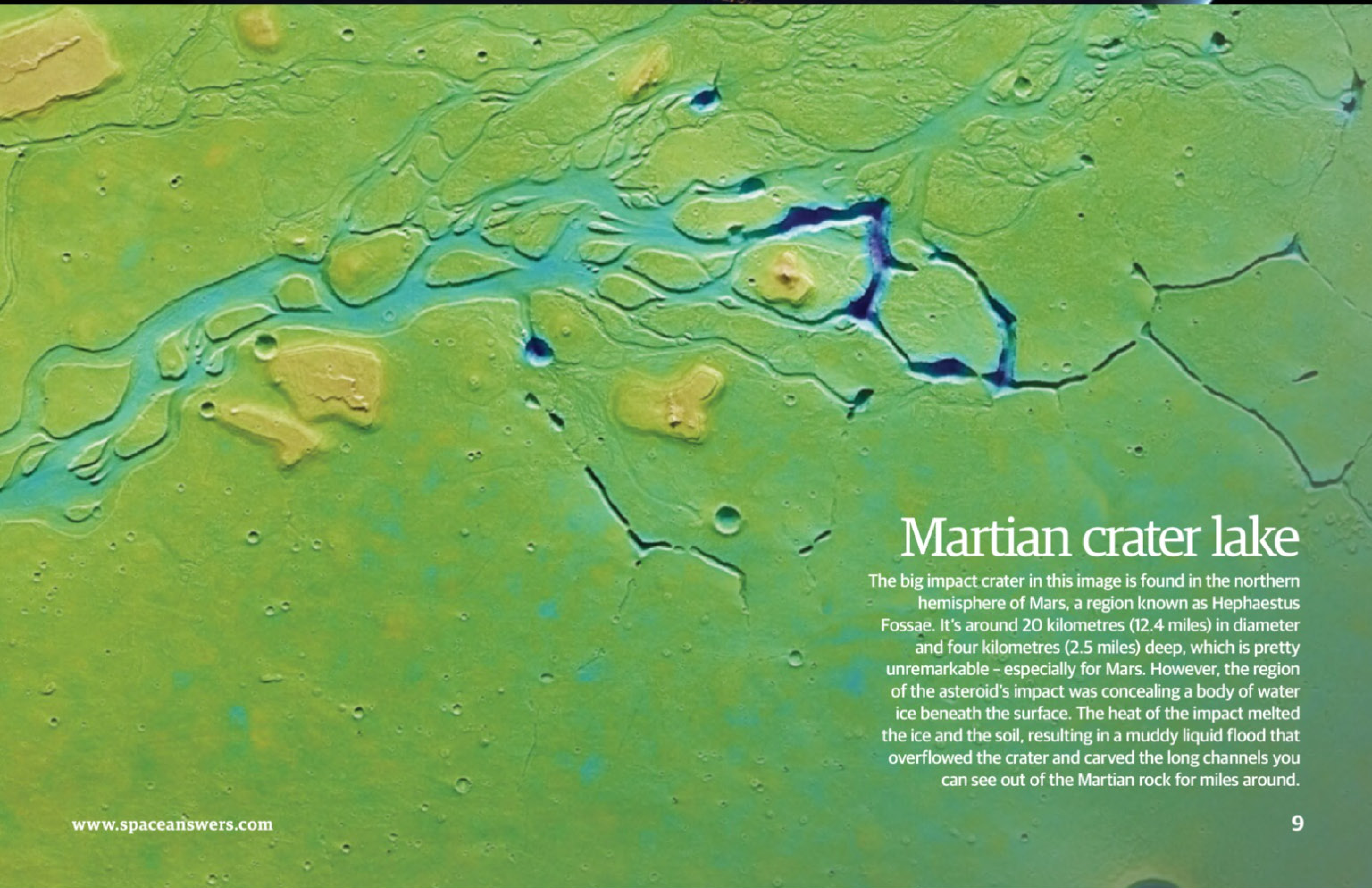
Young at heart

This is the Flame nebula (NGC 2024), a stellar cloud found around 1,400 light years from Earth in the constellation of Orion. In the centre, the purple spots are young stars aged around 200,000 years old, while moving out to the edges are older stars aged 1.5 million years. This image is a composite of data gathered by the Chandra X-ray Observatory, with infrared data from the Spitzer Space Telescope.



First light

Dawn breaks in the far east as the Suomi NPP satellite gathers data and takes images of artificial light on Earth. By using filters to remove natural phenomena like wildfires and auroras, the glare of city lights has been isolated and can give vital information on energy use and city planning. This data was overlaid on an existing image of the Earth.



Martian crater lake

The big impact crater in this image is found in the northern hemisphere of Mars, a region known as Hephaestus Fossae. It's around 20 kilometres (12.4 miles) in diameter and four kilometres (2.5 miles) deep, which is pretty unremarkable – especially for Mars. However, the region of the asteroid's impact was concealing a body of water ice beneath the surface. The heat of the impact melted the ice and the soil, resulting in a muddy liquid flood that overflowed the crater and carved the long channels you can see out of the Martian rock for miles around.

Courting couple

Here you see two galaxies beginning their multi-billion-year waltz towards becoming a single giant galaxy. The pair, known as Arp 87, is found in the constellation Leo, 300 million light years from Earth. It's one of a huge collection of interacting galaxies snapped by Hubble. NGC 3808A is below, while the smaller galaxy above is designated NGC 3808B. Both show an extremely high rate of star formation that's typically seen when galaxies interact and merge.

Wake up Rosetta

Controllers wait anxiously behind the scenes at the main control room of the European Space Operations Centre in Darmstadt, Germany. After nearly three years drifting through space, having been put to sleep to save power as it orbited far from the Sun, the Rosetta space probe woke up and sent its hugely anticipated signal to mission control. Rosetta is scheduled to rendezvous with comet 67P/Churyumov-Gerasimenko on 11 November 2014.

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11 billion years old, 2.3 times the size of Earth and 17 times its mass, Kepler-10c is a rocky behemoth

> "Just when you think you've got it all figured out, nature gives you a huge surprise"
> **Kepler mission scientist, Natalie Batalha**

Mega-Earth rocky planet discovered

Astronomers have spotted an 'impossible' rocky planet twice the size of Earth in the Kepler-10 system

Scientists analysing data gathered by the beleaguered Kepler Space Observatory have been confused by the discovery of a massive rocky planet.

Kepler-10c is 2.3 times the size of Earth, with a diameter of around 29,000 kilometres (nearly 18,000 miles). It's found in the Kepler-10 system orbiting a G-type (Sun-like) star, 560 light years away from the Solar System in the Draco constellation. The existence of this planet has actually been known since it became a planetary candidate in January 2011, but it's only with recent follow-up observations by the Telescopio Nazionale Galileo HARPS-North instrument on the Canary Islands that scientists were able to determine its mind-boggling mass. Weighing in at 17 times the mass of the Earth, Kepler-10c defies current scientific understanding of the upper limits of mass that a rocky planet can achieve.

Previously rocky giants this massive weren't thought possible, because the huge gravitational force their mass generates should, according to conventional wisdom, form a gaseos envelope that would transform the planet into a gas giant more like Neptune or Jupiter. Instead, Kepler-10c has been observed to be made of rock and other solids with, perhaps, a relatively thin atmosphere. "Just when you think you've got it all figured out, nature gives you a huge surprise – in this case, literally," said Kepler mission scientist Natalie Batalha.

"We were very surprised when we realised what we had found," said astronomer Xavier Dumusque from the Harvard-Smithsonian Center for Astrophysics (CfA). "Kepler-10c didn't lose its atmosphere over time. It's massive enough to have held onto one, if it ever had it. It must have formed the way we see it now."

This Godzilla of Earth orbits its parent star once every 45 days and scientists at CfA have also found a correlation between a planet's orbital period and the mass at which a rocky planet will become a gas giant. This discovery means that more mega-Earths could be discovered.

At nearly 11 billion years old, the Kepler 10 system formed at a time in the history of the universe when there was very little in the way of heavy elements. This shows that planets of this type could form much earlier than previously thought.

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Where did all the antimatter go?

The CERN experiment takes scientists a step closer to answering one of the biggest questions in space

Scientists at CERN, the organisation responsible for operating the biggest particle physics laboratory in the world, have published research that moves us closer to understanding where all the antimatter in the universe has gone.

For the first time, the electric charge of an anti-atom (created in CERN's Antiproton Decelerator) has been measured to a high level of precision in CERN's ALPHA experiment. By studying the electric charge on an antimatter particle, the differences between matter and antimatter can be discerned. These should be identical, apart from the type of charge they hold: a hydrogen atom should have proton with a +1 charge and an electron with a -1 charge, while antihydrogens should have a -1 antiproton and a +1 positron.

"This advance was only possible using ALPHA's trapping technique," said Professor Mike Charlton, lead UK ALPHA scientist from Swansea University. "We are optimistic that further developments of our programme will yield many such insights in the future."

Conventional thinking states that the Big Bang should have created an equal amount of antimatter for every particle of matter in the universe, but the only antimatter scientists have ever observed are the particles created in cutting-edge laboratories like CERN. Discovering where it all went is the goal of many scientists, as it could radically change physics forever. ●

CERN's Antiproton Decelerator slows antiprotons down and sends them to various experiments

SAVE RHINOS NOW

Help us Save Rhinos Now!

Fight poaching today: Join World of Animals magazine on the Save Rhinos Now campaign trail

World of Animals magazine has teamed up with Ol Pejeta, east Africa's largest black rhino sanctuary, to raise awareness and help prevent the horrific poaching of this endangered species.

Ol Pejeta Conservancy is dedicated to securing habitats for the purpose of protecting wildlife. The not-for-profit organisation takes care of over 100 rhinos, hosts breeding programs and has the capacity for many more animals that are in need. As of issue 7 of **World of Animals** magazine, ten per cent of the magazine's profits will be donated to Ol Pejeta to help one of Africa's most iconic animals survive.

To follow this vital campaign, head over to **www.animalanswers.co.uk** to get the latest news and information direct from the Conservancy. You can also find a link to donate directly to this worthy cause.

On sale now, issue 8 of **World of Animals** explores the hunting prowess of hyenas, reveals all about the great white shark and uncovers just how Earth's wildlife create their own natural camouflage.

World of Animals magazine can be found alongside digital editions for iOS and Android, available from **www.greatdigitalmags.com**. Be sure to follow the Save Rhinos Now campaign on Twitter (**@WorldAnimalsMag**) and Facebook, (**www.facebook.com/worldofanimalsmag**). ●

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Ten per cent of **World of Animals**' profits will help stop rhino poaching

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Ancient worlds found nearby

A team of international scientists has discovered two new planets orbiting a nearby star. Kapteyn's star is one of the oldest found in the solar neighbourhood. Both planets are many times the mass of Earth, though the smaller of the two could sufficiently support liquid water.

New supernova detected

Data from the Spitzer Space Telescope has revealed a rare class of type-Ia supernova. N103B is found 160,000 light years away in the Large Magellanic Cloud and unlike common type-Ia supernovas, which feature two colliding white dwarfs, N103B was made by a dwarf feeding off a red giant star.

IRIS spots huge solar eruption

NASA's Sun-watching Interface Region Imaging Spectrograph (IRIS) has recorded its first coronal mass ejection (CME), which erupted out of the Sun at speeds of around 2.4 million kilometres (1.5 million miles) an hour. These massive eruptions occur more often at the peak of the 11-year solar cycle.

LAUNCH PAD

YOUR FIRST CONTACT WITH THE UNIVERSE

The ESA's new Sun-watching spacecraft will need to endure stifling-hot temperatures

Artificial Sun tests Solar Orbiter

One of the most important and challenging tests that the ESA has subjected its Solar Orbiter mission to so far is the artificial Sun.

The spacecraft will orbit the real Sun at around a quarter of one astronomical unit, approximately 38 million kilometres (24 million miles) away. This may seem like a lot but at that distance, sunlight is 13 times more intense than it is on Earth, subjecting the Solar Orbiter to temperatures of up to 520 degrees Celsius (968 Fahrenheit).

To test the thermal protection of the spacecraft's multilayer, insulation, foil Sun shield, it was placed in the ESA's Large Space Simulator. To simulate the conditions of space, the black walls of the chamber were chilled to -170 Celsius degrees (-274 Fahrenheit) while 19 25-kilowatt xenon lamps blasted the shield with a simulated beam of sunlight via an array of mirrors. While the Sun shield was tested, infrared cameras measured its temperature, while photogrammetric cameras monitored the surface of the shield for the slightest movement.

The Solar Orbiter will perform high-resolution studies of the Sun and its inner heliosphere when it launches in 2017. By allowing scientists to observe the Sun's polar regions closely, it's hoped that we will be able to understand how the Sun creates and controls the heliosphere. It will also return unprecedented views of solar storms and the Sun's far side. ■

Space junk is now a major hazard for future missions

ESA investigates dead satellites

The European Space Agency probes mystery of how space junk behaves

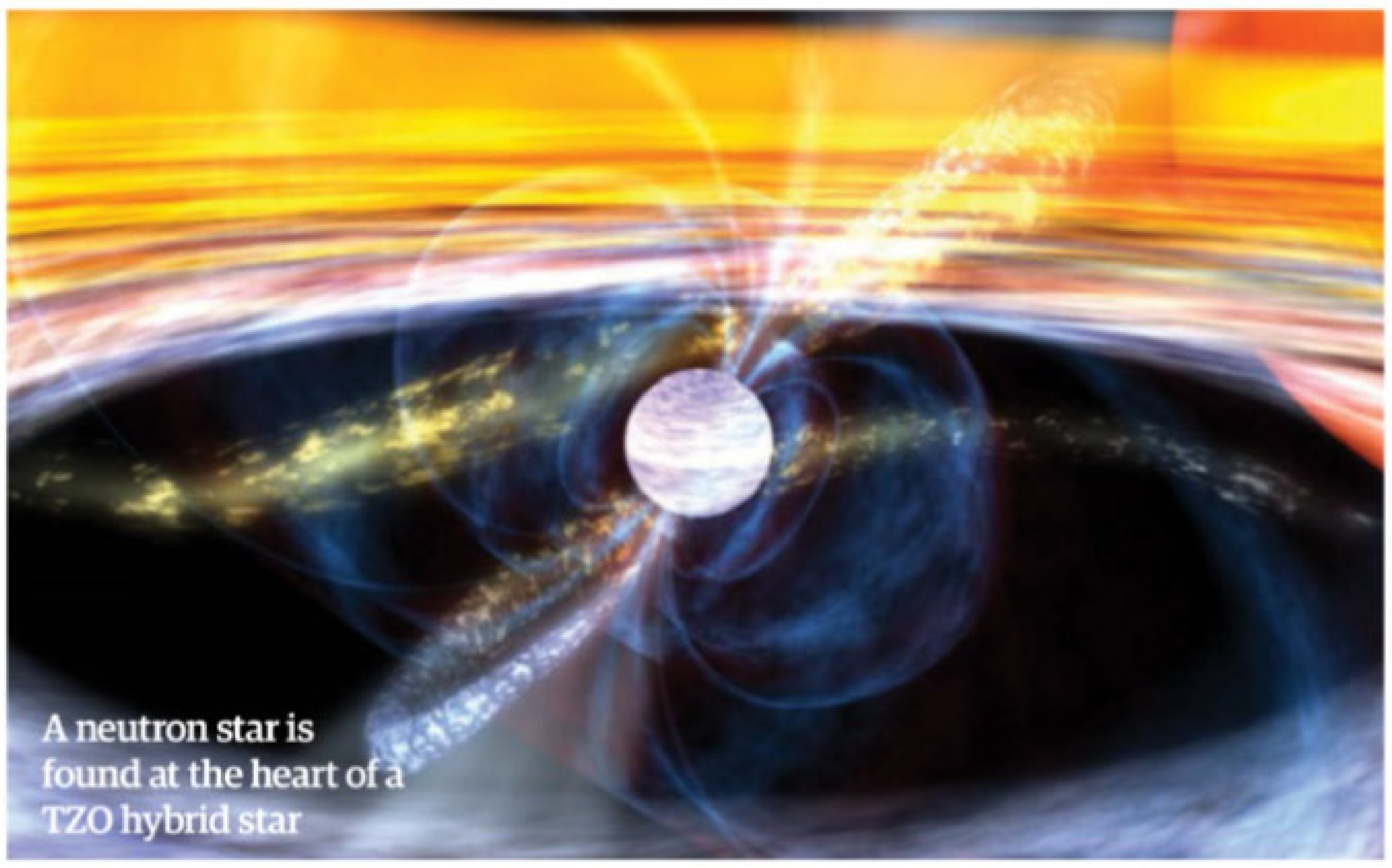
The Clean Space initiative has been tasked with both protecting and clearing up the orbital region around the Earth by the ESA. A part of this project is investigating how dead satellites and other objects move through space, as currently we're unable to predict their movements. By making large and dead objects, such as satellites and upper launch stages, more predictable, Clean Space will be able to track and help clear our mess.

Ground-based observation techniques combined with computer analysis will be used in the study. This will include laser-ranging with a network of ground-based stations in various locations across the globe, bouncing laser beams off a target satellite's retroflectors. Optical and radar satellites in orbit nearby the target could also be used.

By making multiple observations of this type, a profile of dead object behaviours under certain conditions can be built up and hopefully used to predict future movement. These conditions include atmospheric drag, fuel leaks, the movement of leftover fuel and the tiny push of sunlight. ■

Scientists spot strange hybrid star

40-year-old theoretical Thorne-Żytkow object discovered



A neutron star is found at the heart of a TZO hybrid star

In 1975, physicist Kip Thorne and astronomer Anna Żytkow proposed a new hybrid type of star. Dubbed a Thorne-Żytkow object, or TZO, it was made up of a red supergiant star with a neutron star at its core. But these rare objects have been completely theoretical until now.

Using the 6.5-metre (21.3-foot) Magellan Clay telescope in Chile, astronomers studied the light from red supergiants. They were looking for signatures in the electromagnetic spectrum that would show a distinct chemical signature at their core.

This signature was found in a red supergiant star designated HV 2112 in the Small Magellanic Cloud. The elements lithium, rubidium and molybdenum were detected in much higher quantities than expected, indicating that HV 2112 could in fact be a TZO.

"Since Kip Thorne and I proposed our models of stars with neutron cores, people were not able to disprove our work," said Anna Żytkow. "If theory is sound, experimental confirmation shows up sooner or later. So it was a matter of identification of a promising group of stars, getting telescope time and proceeding with the project."

These rare stars are thought to form by the interaction of two massive stars in a close binary system. During supernova, the neutron star that forms is effectively swallowed by its partner red supergiant and sinks into its core. Where the red supergiant was previously fuelled by nuclear fusion, it now derives its energy from the strange activity of the neutron star that is now found at its core. ■

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The rocket engineer
The mission controller

HOW TO BECOME AN ASTRONAUT

...plus other cool space jobs

Is becoming an astronaut your dream? Want to spend your days exploring the stars? Find out how your career in the space industry could lift off

Written by David Crookes

So much has happened since Neil Armstrong set foot on the Moon in 1969. Today, we have the International Space Station, plans to send manned missions to Mars, telescopes that can see beyond our Solar System and agencies across the world aiming to put men and women into space. If you would love to explore space as a career, you couldn't have picked a better time, especially given the number of private space tourism companies looking to send members of the public high above the Earth's surface.

A word of warning: it's not going to be an easy ride and you'll be entering a competitive arena of the best and brightest. If there were ever a stark example of why it pays to absorb as much as possible at school, the space industry is it. Unless you have a solid background in science and maths, showing great aptitude for both, many doors will be closed. It may sound negative, but it's very much the harsh truth.

If you make the grade though, the universe is your oyster. Space is one of the most exciting industry areas in the Solar System, with new advances and fresh breakthroughs taking place regularly. Whether you become an astronaut and find yourself on a rocket hurtling to a far-flung planet or love to bury your head in research and test cutting-edge theories, the possibilities are wide open. Who knows – you may even be the one who finally discovers life on another planet.

Over the next few pages we're going to take a look at the various cool jobs you can get stuck into. We speak to the people who are already involved and achieving great things, as well as those who are on the cusp of greatness and have already enjoyed long careers. We also look at some jobs that you may never have considered, all vital to further human knowledge of the universe. Good luck.

The astronaut

Take the next giant leap for mankind

BIO

Jeremy R. Hansen

Canadian Space Agency

Astronauts are trained to go into space either as a commander, pilot or crew member of a spacecraft. Having been selected in May 2009 as one of 14 members of the 20th NASA astronaut class, Major Hansen is one of two active Canadian astronauts. He trains in spacewalks and robotics, takes part in geological expeditions and he has even established a new training program to simulate a week on board the ISS.

Astronauts have a clear aim: to shoot into the darkness of space and explore to further human knowledge of the universe. Of all of the jobs in the space industry, this is potentially the most exciting and certainly the most-recognisable role.

It's not an easy job to get and there are certain barriers in your way before you can even start. Although jobs are increasingly available via private companies, opportunities tend to be restricted given that agencies recruit from their own citizenship. To be a NASA astronaut, you need to be an American citizen, ESA looks for Europeans and the Russian Space Agency wants Russians (Russian astronauts are called cosmonauts). What's more, each one is after a high standard of candidate.

The cost of training an astronaut is huge, so the agencies need to find the very best people from the outset. This is not a role you can learn at university and it will take years of preparation before a successful candidate jets off into space. Even then, flight opportunities are limited.

For those who are successful, a career as an astronaut is hugely rewarding. There are two types to choose from – pilots and mission specialists – but both suit people who want to learn and can do so quickly. Pilots will fly the shuttle and dock it with the ISS, or another satellite that needs servicing or retrieving. These pilots tend to be picked from the armed forces.

Mission astronauts accompany the pilots and work on various research tasks, as well as repairing and maintaining equipment. The role evolves and needs fresh knowledge and understanding as the years go by. The job also needs operational skills, since Astronauts are often put in positions where things aren't going their way, making life uncomfortable, intimidating and scary. The key is how people react to the situation they're in – space agencies want people who can separate emotion from the situation and think critically, looking for solutions.

This means the training is varied and the job is demanding, fun and challenging. You'll find yourself in extreme situations on Earth and in space. You could be flown as part of a team to the Arctic on an aeroplane and left for days at a time to explore and survive, or you could be stationed on the International Space Station where you'll experience weightlessness in cramped conditions. It's all part and parcel of this amazing job.

In space it's hard to think about a typical day, since an astronaut will see 15 dawns every 24 hours. As well as trying to get into a new sleeping rhythm, astronauts need to work. On the ISS this may involve supervising experiments or maintaining station equipment. Work on the ISS is supported by astronauts on the ground, looking at how life in microgravity affects the human body, studying bone-loss or the effects of radiation levels. Spacewalks and robotics figure highly and it all helps to develop systems and processes that will one day see humans set foot on Mars. Astronauts training today may well get that opportunity within the lifespan of their career and there's no greater motivation than that.

Getting accustomed to near zero-gravity is essential

> "Astronauts are often put in positions where things aren't going their way"

CV

Education
You'll need a bachelor's degree in Engineering, Biology, Physics, Maths as well as an advanced degree (Master's level or above).

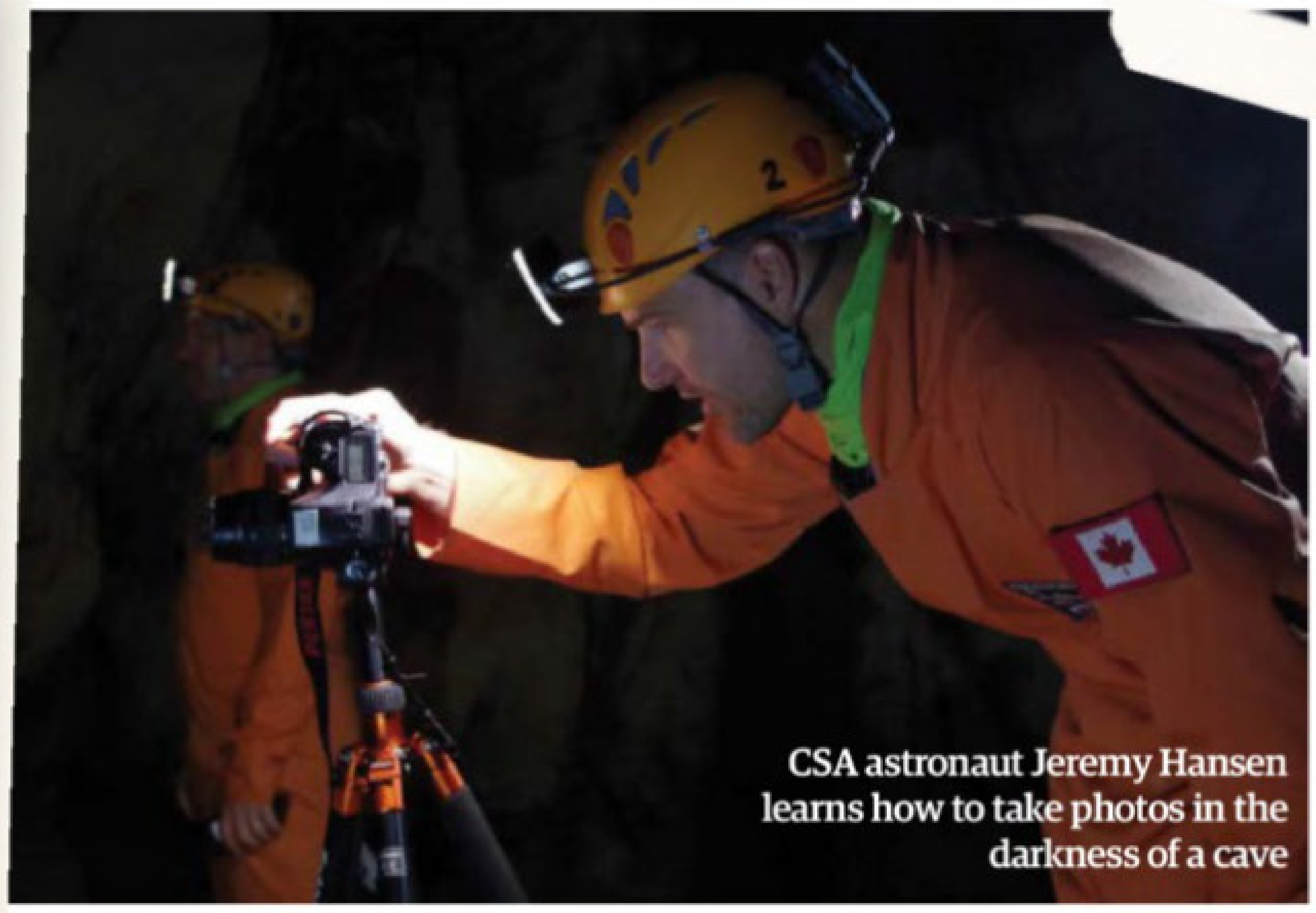
Wings
More than 1,000 hours pilot-in-command time in a jet aircraft, if you wish to be a pilot.

Physical fitness
NASA and other agencies will measure your vision, blood pressure, height and more.

Willingness to learn
Major Hansen believes this is the most vital asset of all.

Inspiring the next generation is also an important part of an astronaut's role

Jeremy Hansen's first EVA run in NASA's Neutral Buoyancy Laboratory


CSA astronaut Jeremy Hansen learns how to take photos in the darkness of a cave

Insider knowledge

What is it like being an astronaut?
Jeremy Hansen: I am trained to go into space by NASA at the Johnson Space Centre in Houston, Texas, but I'm hired for Canada. Currently we're not flying a lot of people into space but, in say five years from now, I think we're going to see some rapid changes developing, particularly with commercial companies getting involved, changing the map of how many people are flying in space and the types of things we're doing with respect to space exploration.

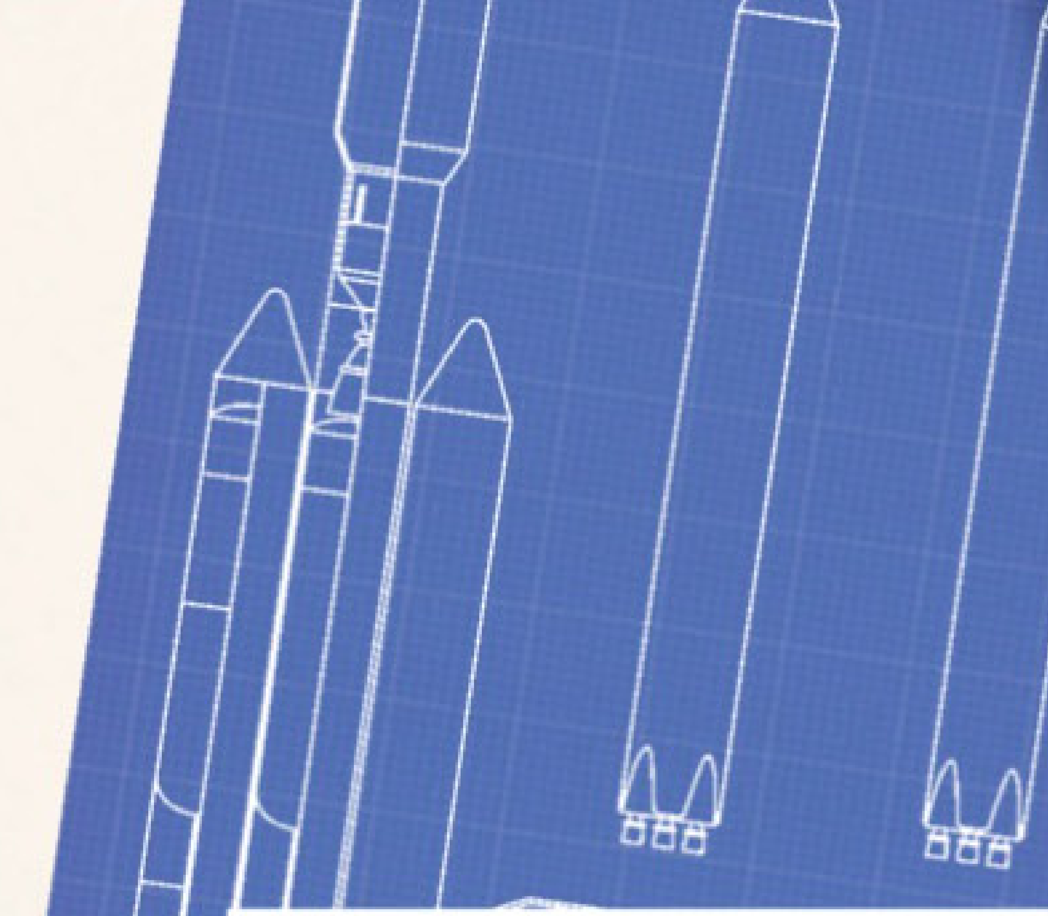
How did you become an astronaut?
JH: I have a specific recollection as a child of looking at a picture of Neil Armstrong standing on the Moon and just thinking that's incredible. It inspired me to fly. As I grew older, I decided I would fly fighter jets, so I served as a CF-18 fighter pilot, having joined the Air Cadet Program in Canada when I was 12. Flight experience is important if you want to be an astronaut pilot: you need at least 1,000 hours pilot-in-command time in a jet aircraft. It meant, when the Canadian Space Agency asked for applications, I could put my name forward. And that's what I did.

What is the training like?
JH: It's very challenging and diverse… I've been in Canada training on a robot arm recently and I'll be doing fighter jet training after that, but then I'll be back in Houston for spacewalk training. I've spent a lot of time studying languages. You need Russian to fly on Russian rockets. The list goes on and on. This past fall I went on a caving expedition where I spent a week learning how to be a caver, and then I spent the next week with five other astronauts living in a cave for an entire week, without a map, doing real science on behalf of other scientists.

Is there such a thing as a typical day?
JH: The most typical days involve systems training for the ISS. The most gruelling ones are in an enormous pressurised pool in Houston, Texas. It's a full-scale mock-up of the ISS underwater and you wear the real space suit they use for spacewalks. It simulates microgravity as best we can. You just spend an entire day in a suit going out and executing a real spacewalk plan, fixing items that have failed…

What do you need to study?
JH: We study geology because we are preparing to go beyond lower orbit. Spacecraft are being designed, techniques are being thought up, we're looking at science that we want to do on asteroids and maybe eventually on the Moon, but certainly on Mars, which is our long-term goal… A lot of this is going to be based on understanding the geology of our Solar System and trying to unravel some of the clues…

Nicolas Verstappen works on launchers for the European Space Agency



Phil Sumrall worked as a rocket scientist at NASA after a chance encounter with legendary rocket scientist, Dr Wernher von Braun, inspired him

Different types of launchers are used for various missions and the technology is constantly being improved upon

The rocket engineer

Could you be the one helping to blast the future generation of spacecraft beyond the next frontier?

BIO

Nicolas Verstappen
European Space Agency
A rocket engineer builds and tests rockets and, as such, it's a dream job for anyone who wants to be hands-on. Nicolas Verstappen is interested in launchers and in sending other people and objects into space, rather than going there himself.

CV

Fundamentals
Ensure you excel at maths and science at school.

Degree-level
Continue with a Physics or Aerospace Engineering degree.

Go the extra mile
Choose a Master's degree with a focus on aerospace.

Develop your skills
Pursue relevant internships or trainee opportunities .

Does it really take a rocket scientist to work with launchers and spacecraft? Actually, yes. Rocket engineers are involved in the creation of rockets, missiles and spacecraft, so the job requires a very particular set of skills, not least an understanding of advanced maths and engineering.

In actual fact, the job of the rocket engineer is to take knowledge from many disciplines such as maths, physics, chemistry, statics, dynamics, loads, aeronautics, flight mechanics, electricity, magnetism, thermodynamics and many others. They have to apply all this to practical systems that can transport humans and cargo into space, as well as between particular points high above Earth's surface.

This requires attention to detail, much hard graft and the ability to operate as a team. The day-to-day work involves attending technical or project meetings, taking part in design reviews and, because of the fascinating nature of the job, engaging in communication, education and public relations activities to promote whatever agency a rocket engineer works for to a wider audience. There will be lots of processes to follow and so a methodological mind with a spark of genius will stand you in good stead.

The rewards, thankfully, are potentially great. Imagine being in the position Phil Sumrall found himself in when he joined NASA in 1962. Just a year earlier President John F. Kennedy had committed the United States to landing a man on the Moon and returning him safely to Earth in that decade. "When I joined the Marshall Space Flight Center, its role in the Apollo Program was to develop the Saturn family of launch vehicles, the largest of which was the mighty Saturn V that was to enable humans to leave low Earth orbit for the first time," he tells us. "No launch vehicle of that scale had ever been designed and built before and the schedule was very tight."

Even though he was a junior member of the team, he felt the pressure to be successful and he worked very long days on the dynamics and control analyses of the Saturn V moon rocket, with each day posing a challenge. "I can't even describe the feeling that I had when Neil Armstrong stepped down on the Moon and I knew that I, along with hundreds of thousands of others, had some small part in the achievement," he says.

The greatest challenges in rocket engineering come from attempting processes that have never been done before and there is also great delight at working on technology that proves to be widely useful for all of mankind. People use the technology created by rocket engineers without even knowing it, with GPS being a particularly good example. Space applications grow and are constantly being funded, creating a challenging environment, while also offering a degree of job security.

With the rise of private space-exploration companies, the scope for employment is getting ever wider. Rocket engineers can help design and test ever more-efficient ways of getting into space. Private companies offer apprenticeships for school-leavers, giving them a great understanding of mechanical design, manufacturing and testing before they decide on a specialism.

"If you can watch a rocket fly and don't get a little choked up, there are probably other fields that you'd be better suited to pursue," says Sumrall. "It isn't the easiest way to build a career, but it has been a wonderful and rewarding life's work for me. Ultimately, I believe that it is our destiny to expand human presence into the Solar System and eventually beyond. If a person is driven to be part of that great adventure, we will need rockets to get there. No rocket engineers, no rockets!"

> "If you can watch a rocket fly and don't get a little choked up, there are probably other fields that you'd be better suited to"

Insider knowledge

What got you interested in rockets?
Nicolas Verstappen: I've always been very interested in aerospace and astrophysics in general, so science is very much what I like. I remember when I was seven watching the first Belgium astronaut Dirk Frimout on television and he was a payload aboard the American space shuttle Atlantis for the Spacelab mission dedicated to NASA's Mission to Planet Earth. That was in March 1992 and that day I thought I wanted to work for space. I discovered the most efficient and interesting way to work with the space-related subjects was to become an engineer.

What do you enjoy about the job?
NV: Access to space brings many benefits and that's why I chose to become a rocket engineer. Exploration provides greater knowledge: knowledge of our Solar System, as well as better navigation and telecommunication systems. This is only possible because we have the launchers. They are capable of placing satellites accurately into space, so the benefit of space exploration has expanded in ways that could not have been envisaged so many years ago.

What would you say it takes to be a good rocket engineer?
NV: You have to be excellent in solving technical problems and you have to think of everything at the same time. You really have to rethink over and over existing solutions and sometimes you come up with a really out-of-the-box solution that's needed. If you find a solution that no one else can come up with, that simplifies a complex system, you're a good engineer.

What's the most amazing thing you've done?
NV: Europe has developed a range of launchers and has its own launch base and I think for any rocket scientist the most amazing thing is to attend the launch of the rocket you are working on. The most exciting part is the final countdown because you are so much aware of everything that could go wrong, of all the glitches that could occur. It's something very exciting. It gives you the opportunity to see concretely what you're working on and what you're working for.

The astronomers

Unlock the secrets of the universe from your desk

BIO

Jorge Vago

European Space Agency

A planetary scientist studies Solar System objects like planets, moons, comets and asteroids, looking at their history, composition and dynamics. Jorge Vago is the ESA project scientist for the ExoMars mission, preparing and co-ordinating the scientific work for the rover.

Planetary scientist

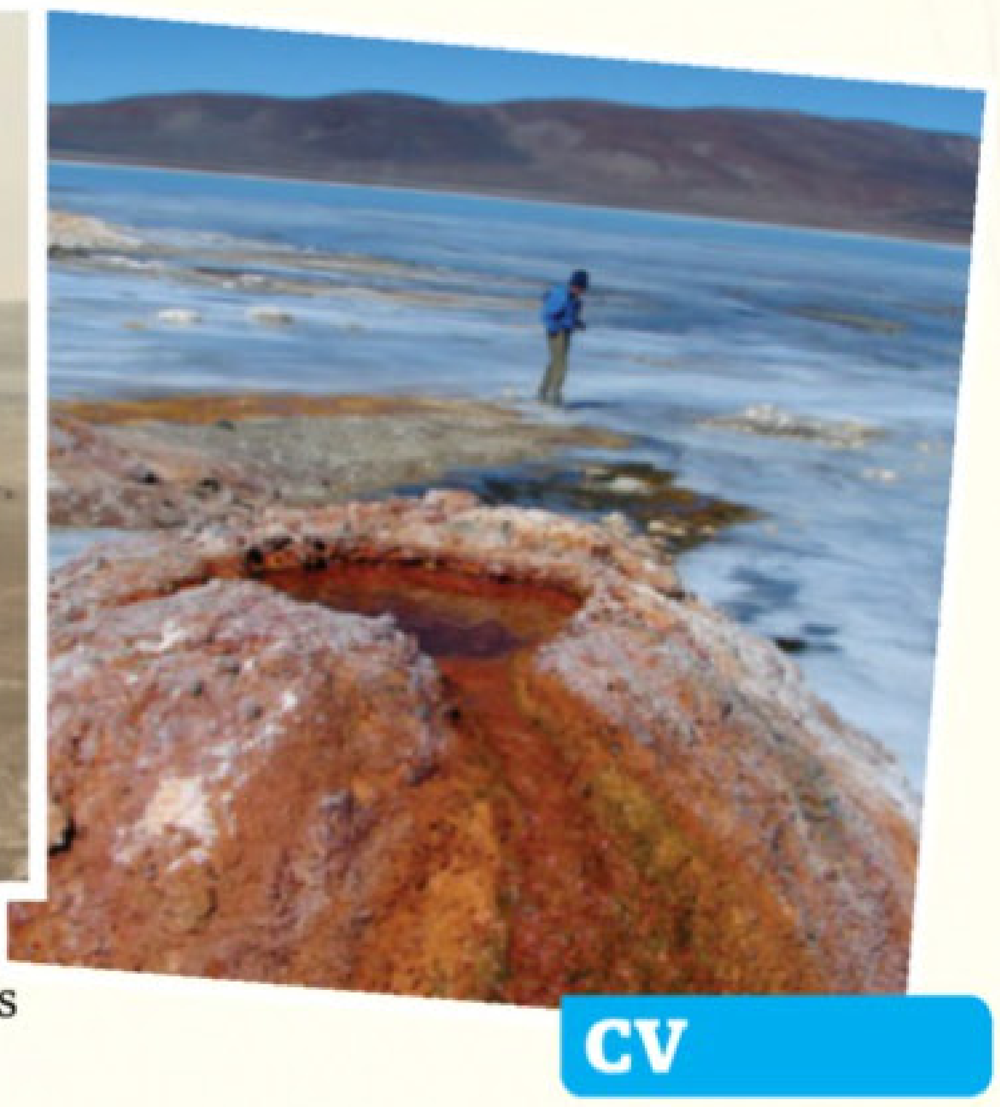
Just reading **All About Space** shows you have an inquiring mind and a keen interest in the universe, but for those who want to delve deeper, a career studying the properties and characteristics of the planets, rings and smaller bodies of our Solar System is an exciting prospect. It doesn't really matter what your initial discipline is, as long as it has some aspect of science. Once you have a PhD in the field of planetary science, you are ready to begin a career in research.

University work is challenging and adds to the body of knowledge of planets. Working for a space agency puts that knowledge to the test. There may be opportunities to get stuck in and look at proposals for rover landing sites, for example, hopefully delivering fresh research data. Engaging in workshops and discussions along with other scientists will also form a large part of your work.

Planetary scientists also look closer to home to help with research. You could be going on a geology expedition in the Australian desert, experimenting in simulated zero gravity or launching small rocket missions. Big missions will take up a lot of time and energy but they will bring big rewards.

In agencies, you will cover a broad canvas so, on a project like ExoMars, there will be various lines of research and lots of groups working in different areas from which you can draw expertise. In pure academia, you have a chance to become an expert in a particular field, however, such as a certain instrument technique. This will suit those with a passion for more specialised research.

This is the planned ExoMars rover that is set to land on Mar's surface in 2018



Jorge Vago is a planetary scientist working on the ExoMars mission that tackles fundamental questions about the planet and the possibilities that life may have existed on Mars early in its history

CV

School basics
Ensure you have a solid background in physics, maths, chemistry and possibly biology.

Degree level
Go to university and study for a degree in Physics, Astrophysics or Geophysics.

Advanced study
Complete a PhD, perhaps focusing on planetary physics or plasma physics.

Developing skills
Compete for a short-term research fellowship to gain more experience.

Research experience
Look for long-term posts in research roles.

Insider knowledge

What got you interested in the field?
Jorge Vago: I got it into my head that I wanted to be an astronaut but I grew up in Argentina and there the possibilities to become an astronaut were limited, so initially I went for engineering. The Planetary Science part came about when I finished my engineering degree and I went to the US to study more.

Is there a single path to your role?
JV: Different countries have different approaches in terms of education. For example, Italy, Spain and to a certain degree France have a broad, general approach and cover many subjects. In other countries, students concentrate early on in a certain discipline. This produces different types of scientists right out of a university. Either can be good, depending on what you want to work on.

How do you structure your day?
JV: I divide my day between responding to a gazillion emails related to the project and working on certain more-scientific aspects. For example, one of the big things this year is the landing site selection for the 2018 ExoMars Rover mission. Another chunk of time, around 10 to 20 per cent, goes into following what the project team does in terms of mission development. This involves discussing mission design details with the project manager and managers of the various elements in the mission. There's very little time left for what you might call actual research or creative stuff.

What would you say your job is?
JV: The job of project scientist is to act as a link or nexus between the scientific community working in the mission and the project team implementing the mission. The scientists want to be sure they're in a position to do great science with the mission and they're choosy in what they want and very specific, but the project has to deliver technical excellence on time and within the given budget. For this they rely on a large industrial team, of many tens of companies and providers whose work they need to co-ordinate. The project scientist has a very difficult job.

What's your greatest achievement?
JV: Professionally, the greatest thing I'll ever do will be to land the Rover on Mars and start drilling. If we can find organic molecules in the sub-surface, that would be the most amazing thing, so that one is yet to come.

The Herschel Space Observatory with a stellar nursery in Aquila, the Eagle

CV

Extra lessons
Sign up for science and advanced maths courses at school and college.

Degree level
Apply for a degree course in Astrophysics at a reputable university.

Advanced study
Continue in academia and complete a Master's degree.

PhD-level studies
Stay on and study for your PhD, engaging in high-level research. You should then begin a post-doctoral research job in academia or with a space agency.

Pilbratt says Herschel will bring a big step forward in our understanding of how stars and galaxies form and evolve

The European rocket Ariane 5 containing the Herschel and Planck satellites

Astrophysicist

BIO

Göran Pilbratt
European Space Agency
Astrophysicists apply the laws of physics to understand the workings of the universe. They observe galaxies, planets, exoplanets and stars. The term astrophysics can encompass many disciplines, including mechanics, relativity, nuclear and particle physics. Herschel project scientist Göran Pilbratt from ESA looks at how stars and galaxies form and evolve.

Have you ever gazed at the stars, yet sought not to merely view but understand them? Astrophysics lets you delve into how the universe works, enabling you to explore how it began and changed over time.

Although their discipline falls under astronomy, astrophysicists study everything outside of the Solar System, whereas planetary scientists tend to study everything within it.

Astrophysicists look at the physics of the universe and how objects within it interact either by coming up with theories or testing them using computer simulations. They benefit from huge and expensive projects such as NASA's Hubble Space Telescope, the Chandra X-ray Observatory, the Spitzer Space Telescope, ESA's Herschel Space Observatory, the XMM-Newton X-ray observatory and INTEGRAL, the International Gamma-Ray Astrophysics Laboratory. Each of these enables a lot of further-reaching insights into the mysteries of space.

University is a perfect place for an astrophysicist to start – here you'll be able to conduct research spanning large time and length scales, study black holes or gain a deeper understanding of dark matter, astroparticle physics or cosmic microwave background radiation.

One thing is for sure, it's not easy, nor can you quickly build up expertise. It can take up to a decade after leaving school to accumulate the knowledge you need and it's for this reason that astrophysicists tend to stay in their jobs for a long time – with few vacancies. If you like the idea of a role in research and spending the bulk of your time trying to find fresh insights that explain astrophysical phenomena, this is the area for you.

Insider knowledge

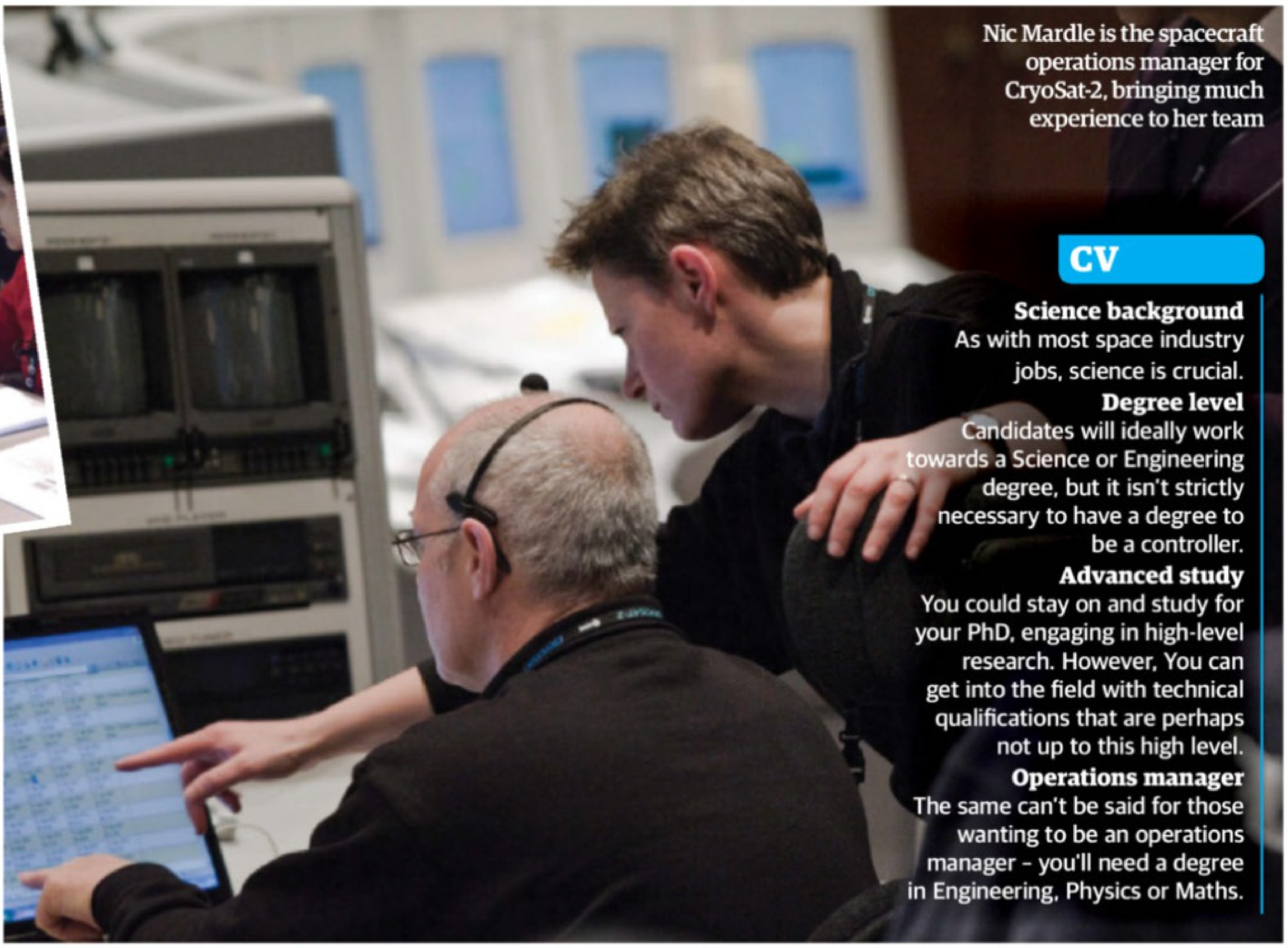
When did you become interested in the field?
Göran Pilbratt: It's actually something I've been interested in since I was a child but I was never what sometimes is referred to as an amateur astronomer – I was more into physics…

How did you start working for the ESA?
GP: When you work for a PhD, the standard career path is a fellowship in a university somewhere to continue the research. That was my plan but one of those opportunities was a Post-Doc here at the European Space Research and Technology Centre in Noordwijk, the Netherlands.

What sort of projects do you work on?
GP: I'm a project scientist for a space observatory called Herschel… It's my job to represent and be an advocate of the science to be done by a project and to maximise the science return of a mission in every respect. Early on in the mission, for instance when you're building a spacecraft, that means safeguarding the important requirements of doing science. This can be everything from instruments and temperatures to the size of telescope. When you actually start building something, you start to realise that the mass is too high or the power consumption is too high or whatever, and engineers will want to cut corners and decrease requirements. It is up to a person in my position to defend the requirements that are important for science.

Does your role change during the mission?
GP: The priority is to use the observatory in the best possible way. This is broad and includes many things, for instance by providing information and tools to astronomers to prepare observations, getting the observations executed and providing the resulting data and tools for data-processing and analysis. There's always interaction with people and various committees, such as science teams, time-allocation committees and the astronomers themselves.

Spacecraft operations manager Nic Mardle standing on console with flight team members


Nic Mardle is the spacecraft operations manager for CryoSat-2, bringing much experience to her team

CV

Science background
As with most space industry jobs, science is crucial.

Degree level
Candidates will ideally work towards a Science or Engineering degree, but it isn't strictly necessary to have a degree to be a controller.

Advanced study
You could stay on and study for your PhD, engaging in high-level research. However, You can get into the field with technical qualifications that are perhaps not up to this high level.

Operations manager
The same can't be said for those wanting to be an operations manager – you'll need a degree in Engineering, Physics or Maths.

The mission controller

Could you be the glue that holds an entire mission together?

Mission controllers look after the progress of a satellite or spacecraft sent into orbit. They will initially communicate with it from the main control room before operations switch to dedicated control rooms that are smaller and more tailored for each task. For the European Space Agency, much of this takes place at the European Space Operations Centre in Darmstadt, Germany.

A mission controller is very much at the coal face, interacting on a daily basis with the spacecraft, sending commands, checking the telemetry, making sure that all of the day-to-day processes happen properly and then reacting first when something happens. They oversee various sets of teams, each with different responsibilities such as sub-system and system engineers who may look after the sub-system on a spacecraft or part of the ground segment, lending expertise in a certain area.

Nic Mardle's role as a spacecraft operations manager may see her planning for special operations. She may have to prepare and develop ground segments and constantly have an eye on the future, reading documents to see how something is set up and advancing on it or devising evolutionary plans.

Working in mission control is a constant learning experience. Even though a spacecraft is designed in a certain way, no one can know everything about it so, when something happens, there is a need to learn something new and this could be a completely new sub-system.

The type of people who would enjoy operations are those who like variety and who prefer to feel they're interacting with a spacecraft, rather than working with paper documents and theories. Mission controllers fly spacecraft on a day-to-day basis, sending commands to alter its orbit or altitude, and while they don't touch the spacecraft itself, they monitor the on-board instruments and keep a watch to ensure everything is working properly. This makes the job more applied and less theoretical than a simple design position.

BIO

Nic Mardle
European Space Agency
As a spacecraft operations manager for the ESA, Nic Mardle works on the CryoSat-2 research satellite, ensuring it's properly controlled. The satellite provides scientists with data on Earth's polar ice caps, tracking changes in the ice's thickness. It's one of the many roles within the industry and shows the importance of monitoring our own planet.

Insider knowledge

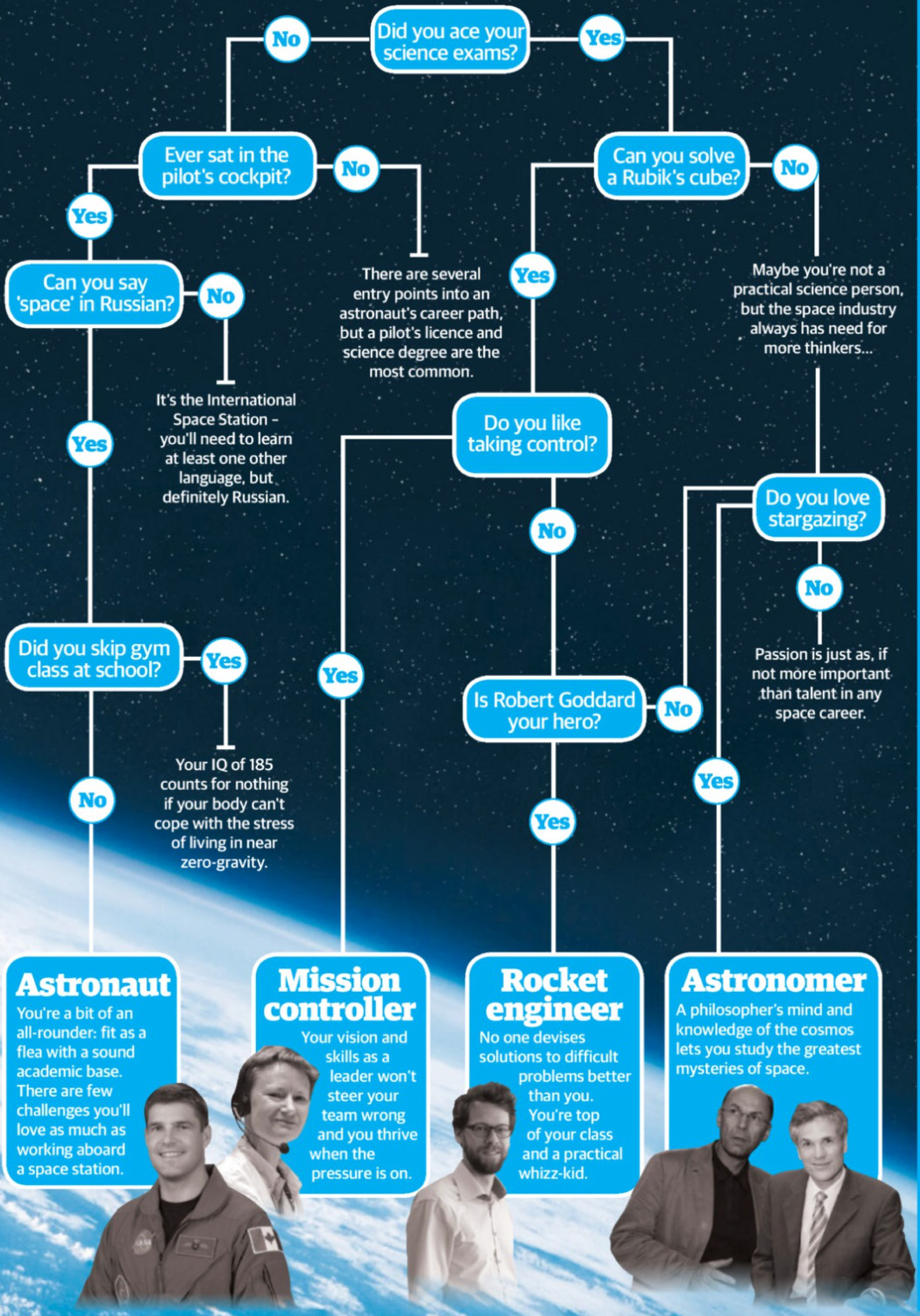
What got you interested in spacecraft operations?
Nic Mardle: I was originally a sponsored student at British Aerospace in Stevenage before I went to university to study Aerospace Systems. I went back to British Aerospace, working in the Assembly Integrations Verification area, where we put spacecraft together, testing and launching them…

Is there a path to that job or do you just need experience?
NM: Operations isn't something that you learn at university. You can learn the engineering or the physics side of it but operations is very specific. Common sense and an engineering background works well. You must learn about each spacecraft individually, how it works, what the constraints are, how it interacts with the ground segment, all these things that they simply can't teach you.

What's your typical day like?
NM: It can be making sure the inputs and outputs are ready for the next weeks of operations. It might be planning for special operations – there are a number that we have to do, whether it's as simple as an orbit manoeuvre or a role campaign that we might do to support scientists on the ground, as well as calibrations of the instrument, or perhaps we have to make a recovery of something.

What would you say are the challenges in building a flight control team?
NM: You have to find people who can work together. We have lots of interactions with different teams so the people who make up a core team have to trust one another and work well together.

Which space career is right for you?



Did you ace your science exams?

No

Yes

Ever sat in the pilot's cockpit?

No

Can you solve a Rubik's cube?

No

Yes

There are several entry points into an astronaut's career path, but a pilot's licence and science degree are the most common.

Yes

Maybe you're not a practical science person, but the space industry always has need for more thinkers…

Can you say 'space' in Russian?

No

It's the International Space Station – you'll need to learn at least one other language, but definitely Russian.

Yes

Do you like taking control?

Do you love stargazing?

No

No

Passion is just as, if not more important than talent in any space career.

Did you skip gym class at school?

Yes

Your IQ of 185 counts for nothing if your body can't cope with the stress of living in near zero-gravity.

Yes

Is Robert Goddard your hero?

No

Yes

No

Yes

Astronaut

You're a bit of an all-rounder: fit as a flea with a sound academic base. There are few challenges you'll love as much as working aboard a space station.

Mission controller

Your vision and skills as a leader won't steer your team wrong and you thrive when the pressure is on.

Rocket engineer

No one devises solutions to difficult problems better than you. You're top of your class and a practical whizz-kid.

Astronomer

A philosopher's mind and knowledge of the cosmos lets you study the greatest mysteries of space.

Five weird space jobs

Chief sniffer

'Nasalnaut' George Aldrich spends his days at NASA smelling the various items that are sent into space. Whether it's a spacesuit, pens, toys, or even adult nappies, he gives them a good sniff to ensure unpleasant odours that intensify in space do not pose health risks for the astronauts.

Tour guide

Perhaps one day you will be uttering, "And to your left, there is Jupiter", since a UK government-backed report in 2010 suggested potential future careers as space tour guides will become available. With the rise in private space companies such as SpaceX, space tourism is set to take off massively.

Space shrink

Being confined in a small space with only a few people miles away from the comforts of Earth can be a burden for astronauts, so it's vital their mental health is monitored and assessed. Space psychologists support crews and help them to cope with isolation and potential boredom.

General helper

This caretaker role advertised at SpaceX has the successful candidate driving forklift trucks, cleaning up work areas and moving heavy equipment as well as "miscellaneous tasks as directed". Being "willing to do anything" is a requirement of this wide-ranging role, but it needs a whole set of skills from plumbing to carpentry.

Visual co-ordinator

Every space HQ needs to look nice, so if you fancy selecting furniture, choosing the colour of paint for the walls and ensuring everything works in visual harmony, then this would be the perfect role for you. After all, we wouldn't want space industry experts to be put off by clashing wallpaper and upholstery.

© NASA; ESA; CSA; Fred Kamphues.

Death Star moon

This small Saturnian moon is one of the most heavily cratered bodies in the Solar System, including one massive impact…

Cassini's causing quite a stir with the images and data it's returning from a certain moon of Saturn these days. But the buzz around Enceladus, and the confirmation of a watery ocean beneath the crust of ice on its surface, has taken our attention away from some of Saturn's other notable satellites. This is despite the fact it's the contrast between Mimas and Enceladus that make both particularly interesting.

Mimas is a somewhat oblate (squashed spheroid) moon that is an average of 397 kilometres (247 miles) in diameter. It's also a pretty low-density object of around 1.17 times the density of liquid water, which suggests that most of this moon is made of water ice, with a small proportion of rock, frozen solid at a temperature of around -209 degrees Celsius (-344 degrees Fahrenheit). This caused an interesting problem for scientists, because not only is Mimas closer to Saturn than Cassini's current favourite target, Enceladus, but it has a more-eccentric orbit that should subject the moon to the greater tidal heating of Saturn's powerful gravitational field.

Geologically speaking Mimas is dead, while Enceladus is still spouting great geysers of water ice into its atmosphere, along with a range of organic compounds. This paradox of Saturn's moons has been explained, in part at least, by the higher density of Enceladus, which likely has a much greater rock content. It's thought that Enceladus' liquid interior and Mimas' solid body are explained by the same theory.

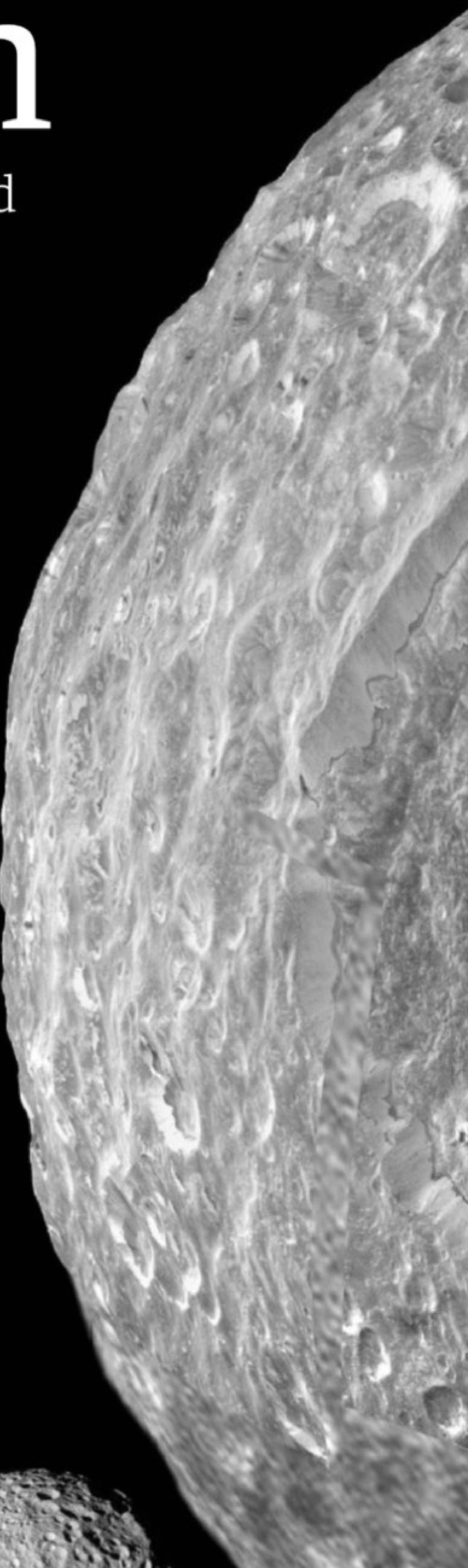
Mimas' permanently frozen state has persisted for billions of years, probably since it was formed. The evidence for this is the dense population of impact structures on its surface, rivalled by few other objects in the Solar System. A sister moon, Rhea, has a comparable number of craters to Mimas, but has no single feature quite as impressive as the enormous Herschel crater. With a diameter of around 140 kilometres (87 miles), walls five kilometres (three miles) high and a floor ten kilometres (six miles) deep, this is by far the biggest crater on this tiny satellite.

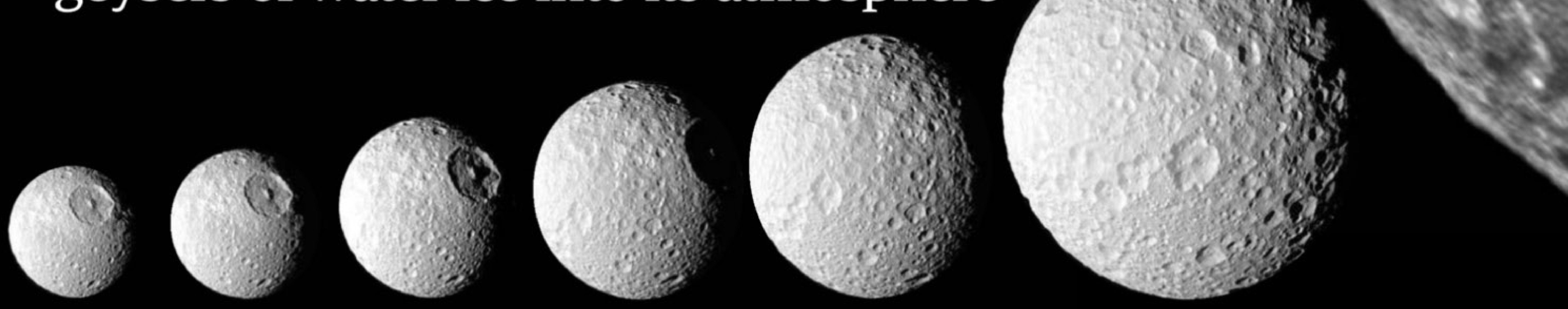
Proportionally, it's one of the biggest impact structures in the Solar System, too. From rim to rim, it's spread across one third of the face of Mimas: if Earth had an equivalent crater, it would stretch around 4,000 kilometres (2,500 miles) wide and have walls over 200 kilometres (124 miles) high. It's a wonder that the impactor that created this crater didn't smash Mimas into fragments, because its legacy literally runs deeper than the 4.1 billion-year-old crater it left behind.

The enormous energy of the impact must have travelled as a shockwave through Mimas to the other side, where massive stresses on the surface cracked open into chasmata, like the Ossa Chasma. The impact likely played a role in the strange temperature pattern of Mimas, which bears an uncanny resemblance to the classic videogame character Pac-Man. Herschel's other legacy to pop culture is also pure coincidence: from certain angles, in images taken both by Cassini and Voyager 1, it looks distinctly like the Death Star from *Star Wars Episode IV*. Voyager 1 discovered Herschel three years after the film was made, so Mimas couldn't have inspired the fictional super weapon.

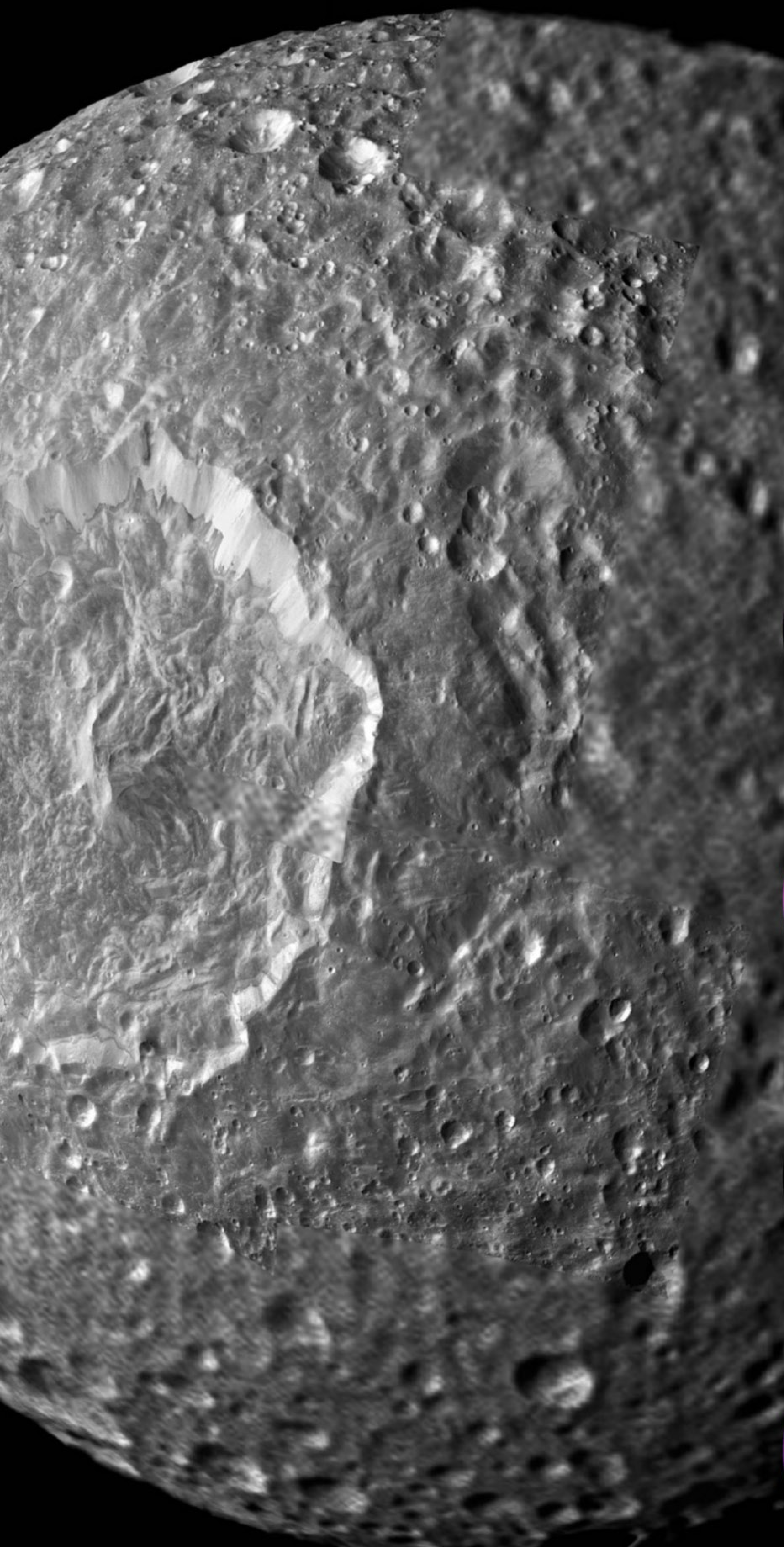
The moon is also responsible for clearing most of a huge region in Saturn's orbit, creating a 4,800-kilometre- (2,980-mile-) wide gap between two of Saturn's widest rings, A and B. This is known today as the Cassini Division. ●

> "Geologically speaking Mimas is dead, while Enceladus is still spouting great geysers of water ice into its atmosphere"



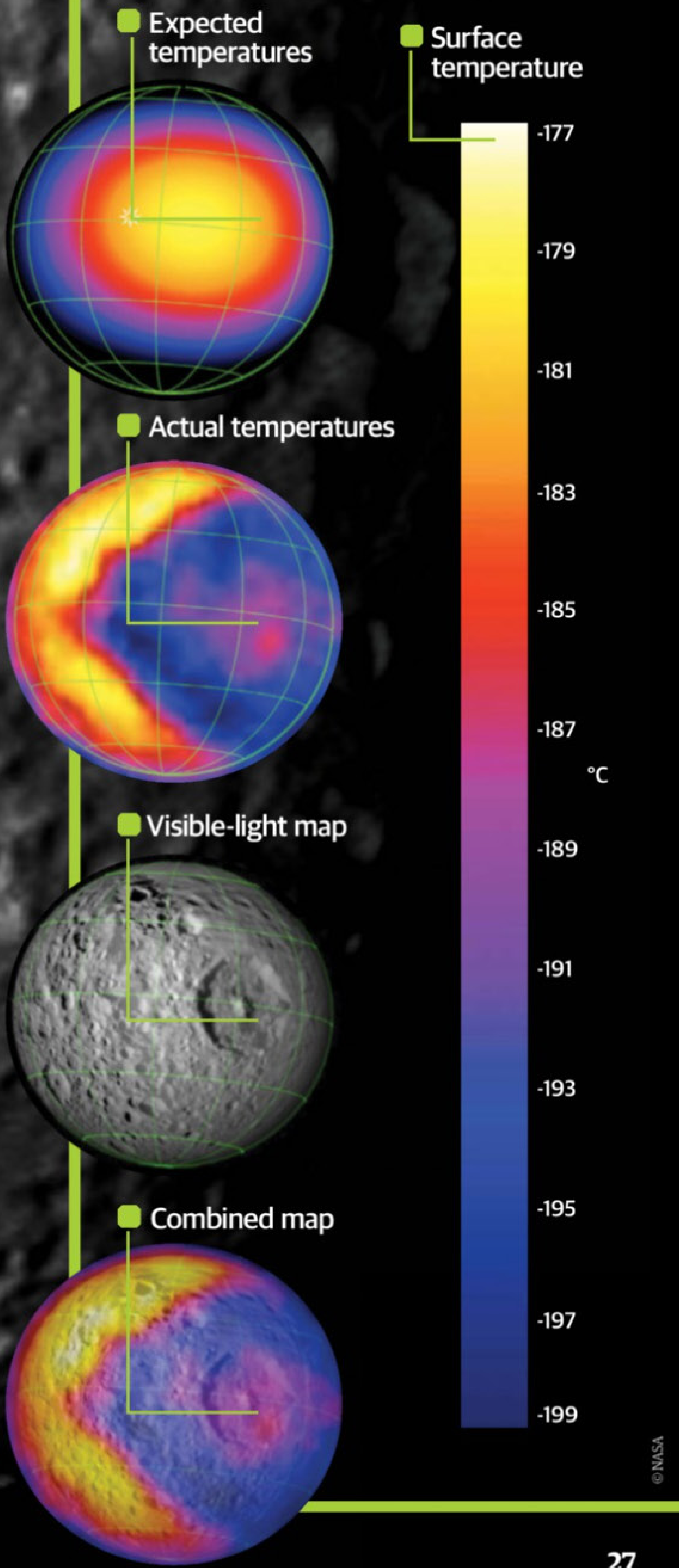


Images taken by Cassini show the different faces of Mimas' heavily cratered surface



Pac-Man Moon

Cassini's composite infrared spectrometer returned an unexpected image to the team at NASA in 2010. Instead of the expected, smoothly decreasing temperature pattern radiating out from the moon's core, Cassini showed a V-shape thermal image for Mimas with a sharp drop-off on the opposite side of the Herschel crater. The cold part of the image is explained by the greater thermal conductivity of materials on the surface of that side, but scientists don't know why it varies so dramatically. With Herschel as the power pill, this thermal image does make Mimas look very much like Pac-Man.



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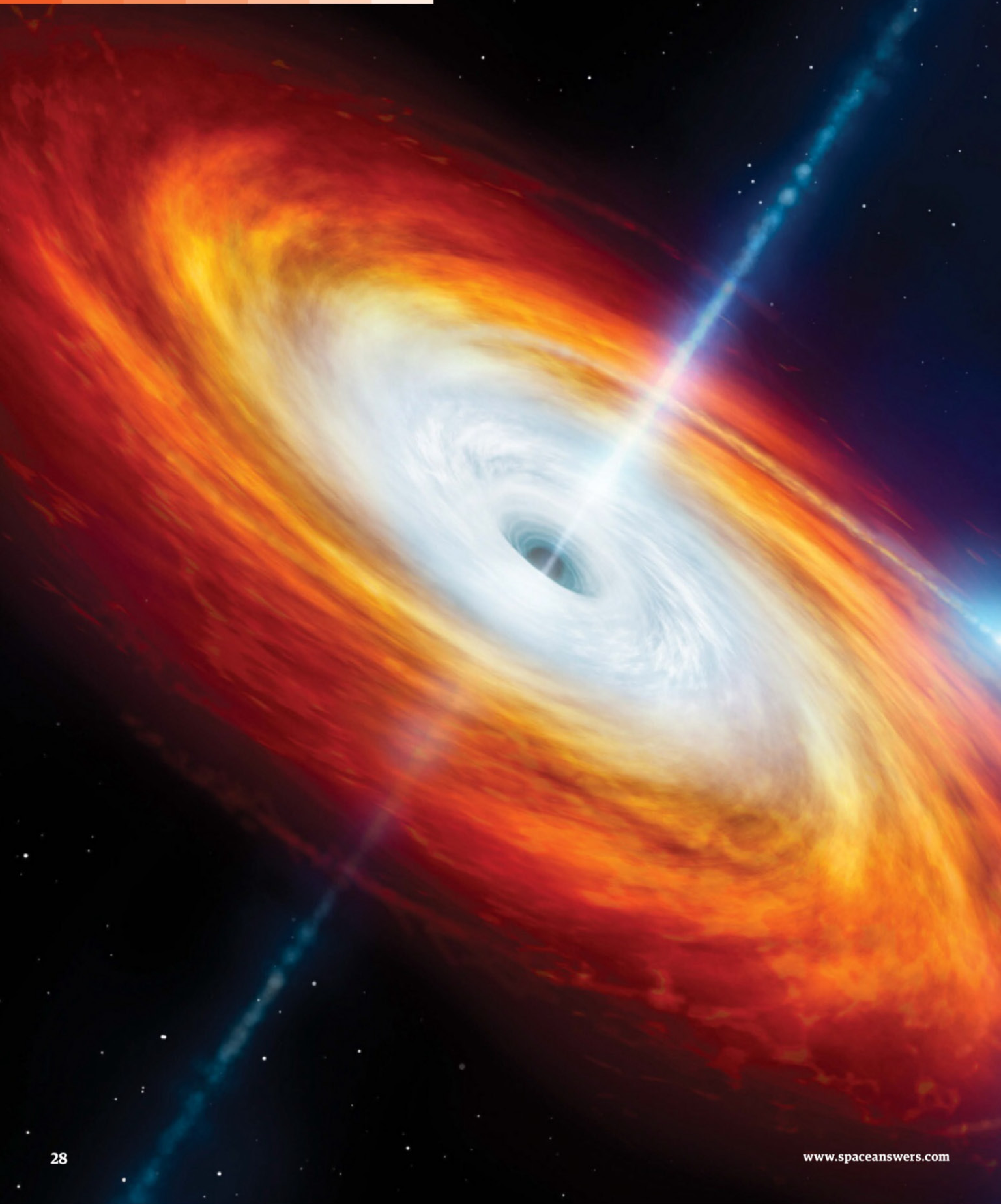


All About...

EARTH'S CLOSEST BLACK HOLE

Embedded in a rich stream of the Milky Way some 6,070 light years from Earth, Cygnus X-1 is a strange binary star containing the nearest known black hole to Earth

Written by Giles Sparrow

The distinctive constellation of Cygnus, the Swan, is one of the most famous in the sky. It includes the famous Northern Cross asterism and flies south along one of the brightest and nearest parts of the Milky Way, parallel to the Cygnus Rift created by a dust cloud 300 light years from Earth. The brightest star, Deneb, is usually taken to mark the swan's tail, while the beautiful double star called Albireo, marks its beak. Fairly obvious wings extend to either side of the swan's body, while another bright star, Eta (h) Cygni, lies in the middle of the swan's neck.

Long-exposure photographs reveal a host of faint objects invisible to the naked eye. Not just stars, there are also clouds of interstellar gas such as the North America nebula NGC 7000 (a star-forming region close to Deneb) and the Veil nebula - the remnant of an ancient supernova explosion in the swan's south-western wing. Invisible radiation wavelengths reveal even more detail - radio telescopes show the full extent of the Cygnus Loop (of which the Veil nebula is a part) and Cygnus A - a pair of huge radio-emitting jets surrounding a distant galaxy. High-energy X-rays uncover the constellation's strangest and best-known object - the black hole Cygnus X-1.

One of the brightest X-ray sources in the entire sky, Cygnus X-1 was discovered in the mid-1960s as a result of an early experiment in space-based astronomy. When Aerobee sounding rockets were launched in 1964 to carry detectors on high-suborbital flights above the atmosphere, they detected eight strong radiation sources from different parts of the sky. Most of them seemed to coincide with distant bright galaxies, but one X-ray source - less than half a degree away from Eta Cygni in the swan's neck - seemed to have no such association.

In 1970 NASA launched the first dedicated X-ray astronomy satellite, Uhuru, with Cygnus X-1 as a priority for further study. Extended observations showed its X-ray output seemed to be fluctuating several times a second, suggesting it must be coming from a relatively small region, perhaps about the diameter of Saturn.

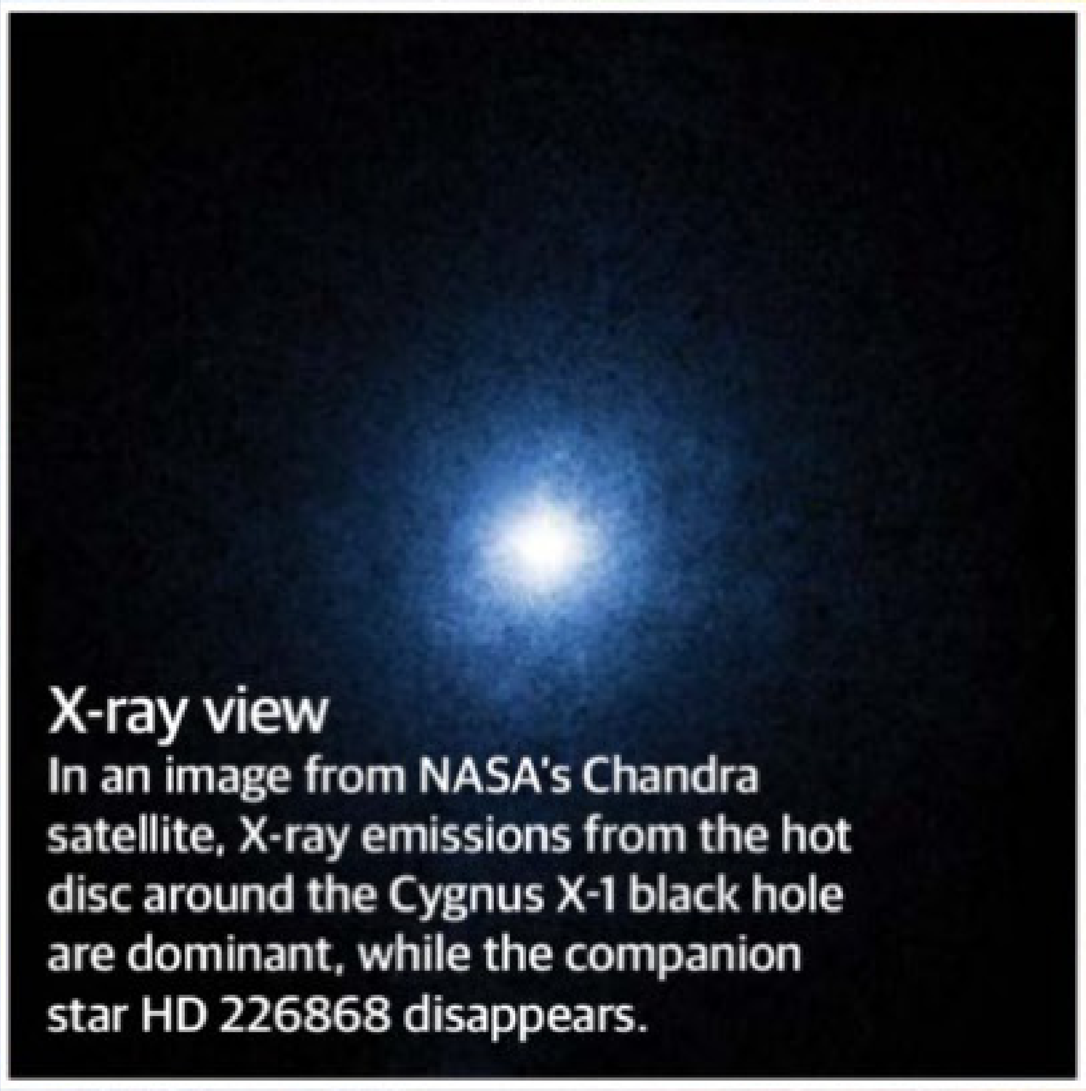
X-rays are notoriously hard to pin down, however, and the precise location of Cygnus X-1 remained elusive. It was only in 1971, when radio astronomers found that Cygnus X-1 was also a radio source, that astronomers got their first clue to the mystery. At first its radiation seemed to be coming from a distant blue supergiant star, catalogued HD 226868. However, within a few months astronomers Louise Webster and Paul Murdin of the Royal Greenwich Observatory, as well as Charles Thomas Bolton of the University of Toronto, independently discovered changes in the visible star's spectrum, indicating it moves back and forth every few days. This suggests that it forms a binary system, locked in an orbital waltz with an unseen object of considerable mass that was otherwise completely invisible.

Black holes (so dense that light cannot escape their gravity) had been theorised as early as the 1780s, but the physics underlying such bizarre objects (and a possible process for their formation) weren't described until the 1930s. Before then, they remained an intriguing object for cosmologists and theoretical physicists, but looking at their measurements of Cygnus X-1, astronomers realised they might be observing a black hole for the first time. ■

Cygnus constellation

The Tulip nebula, Sharpless 101, is just one of the beautiful but faint objects visible in this night-sky wonder

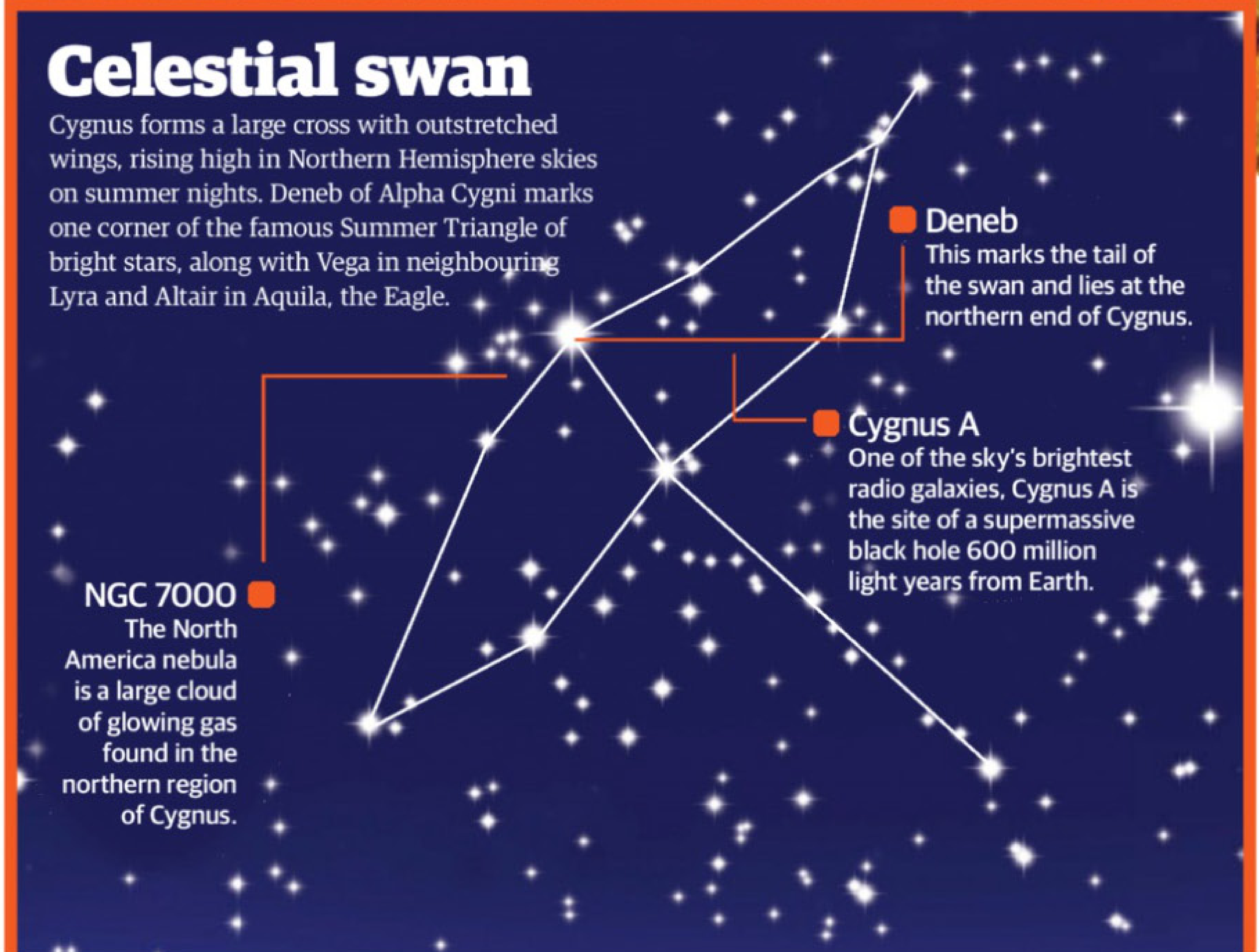
NGC 6871
This small star cluster consists of about 50 newborn blue and white stars.



X-ray view
In an image from NASA's Chandra satellite, X-ray emissions from the hot disc around the Cygnus X-1 black hole are dominant, while the companion star HD 226868 disappears.

Celestial swan

Cygnus forms a large cross with outstretched wings, rising high in Northern Hemisphere skies on summer nights. Deneb of Alpha Cygni marks one corner of the famous Summer Triangle of bright stars, along with Vega in neighbouring Lyra and Altair in Aquila, the Eagle.

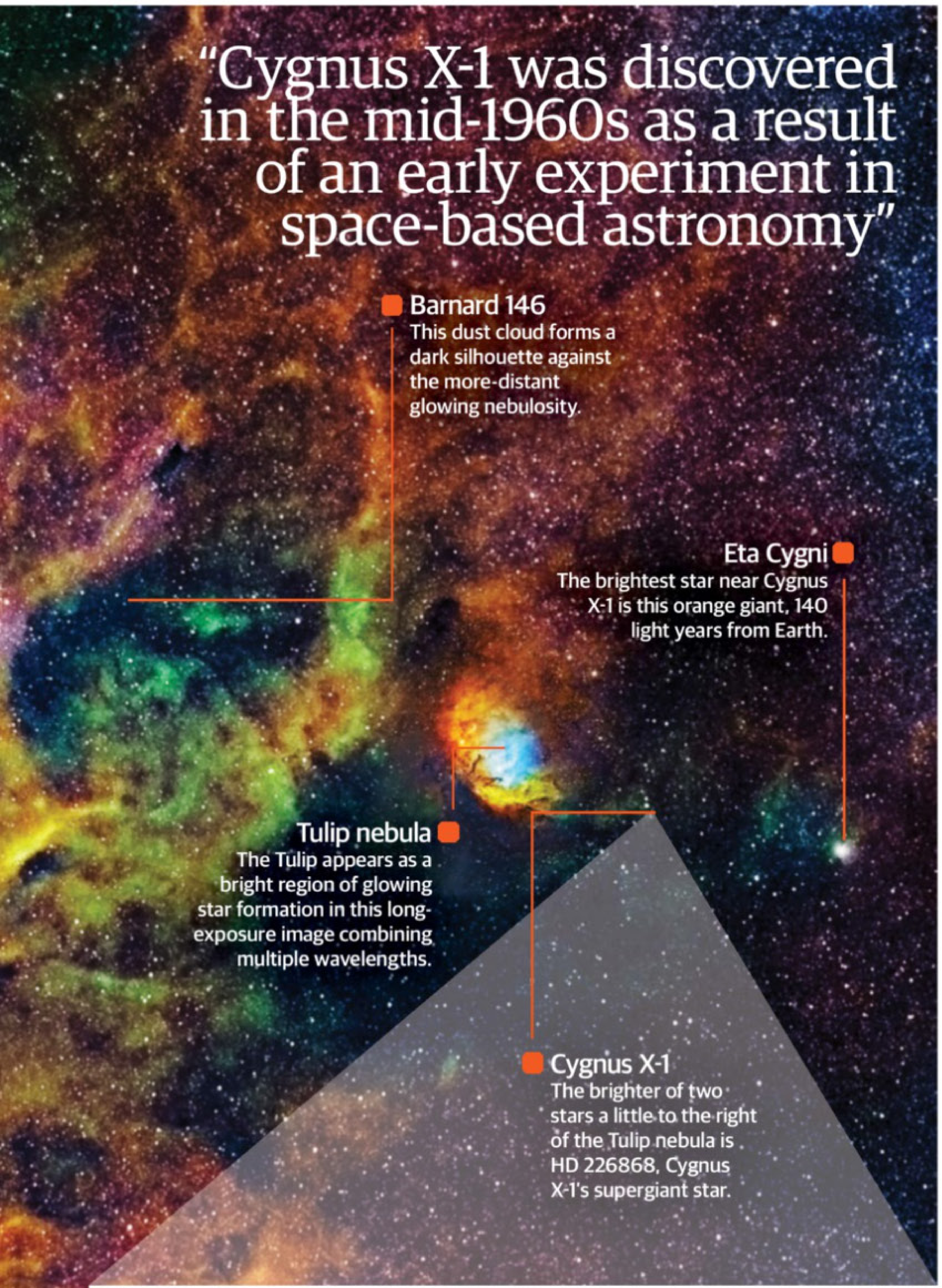


Deneb
This marks the tail of the swan and lies at the northern end of Cygnus.

Cygnus A
One of the sky's brightest radio galaxies, Cygnus A is the site of a supermassive black hole 600 million light years from Earth.

NGC 7000
The North America nebula is a large cloud of glowing gas found in the northern region of Cygnus.

> "Cygnus X-1 was discovered in the mid-1960s as a result of an early experiment in space-based astronomy"

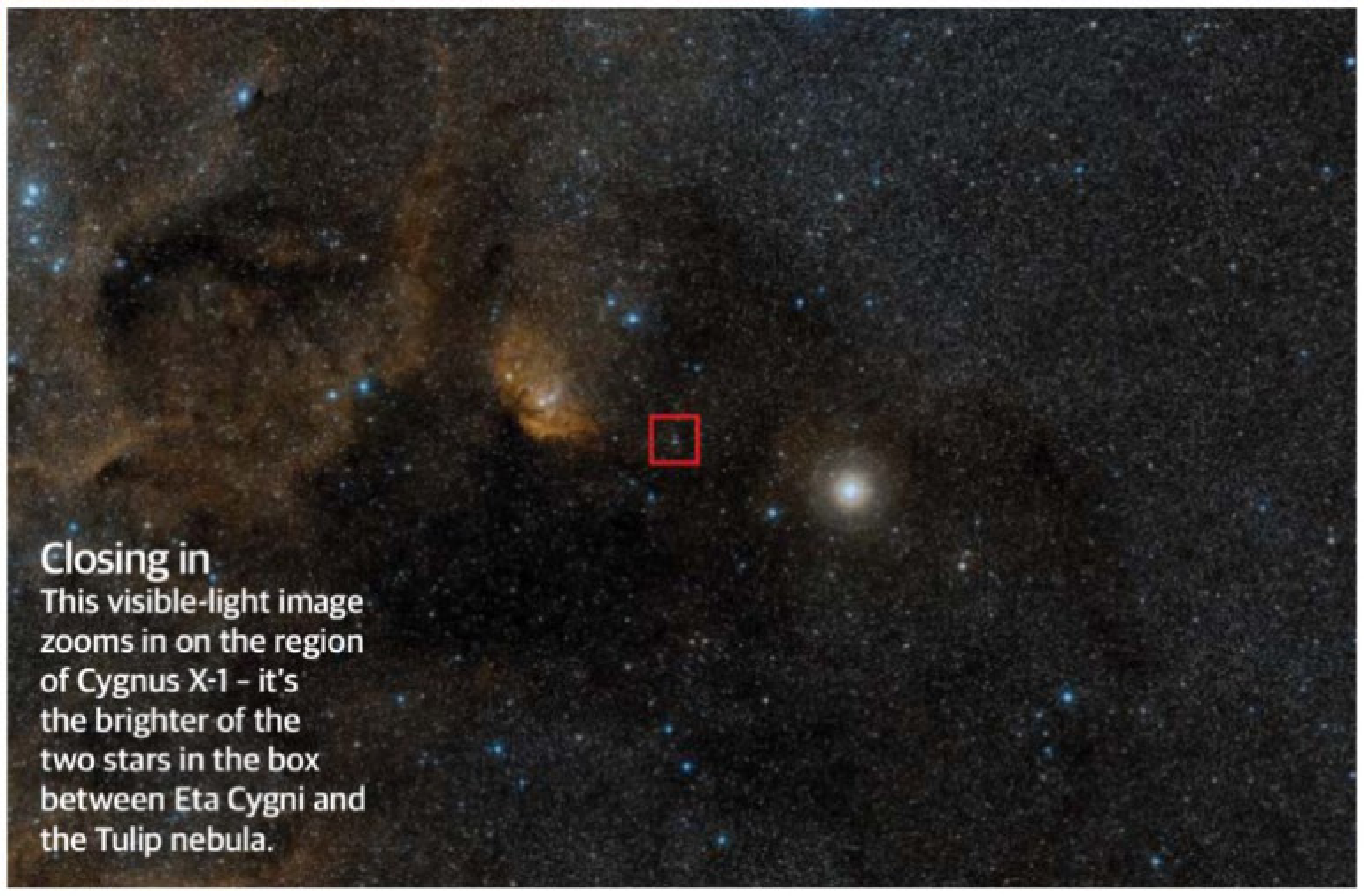


Barnard 146
This dust cloud forms a dark silhouette against the more-distant glowing nebulosity.

Eta Cygni
The brightest star near Cygnus X-1 is this orange giant, 140 light years from Earth.

Tulip nebula
The Tulip appears as a bright region of glowing star formation in this long-exposure image combining multiple wavelengths.

Cygnus X-1
The brighter of two stars a little to the right of the Tulip nebula is HD 226868, Cygnus X-1's supergiant star.



Closing in
This visible-light image zooms in on the region of Cygnus X-1 – it's the brighter of the two stars in the box between Eta Cygni and the Tulip nebula.

Cygnus X-1 by numbers

The nearest black hole to Earth is an extreme object in many ways

6,070 ly

Cygnus X-1's distance from Earth according to the most-accurate radio measurements.

5.6 days

The period in which the two components of Cygnus X-1 orbit each other.

14.8 Suns

The mass of the Cygnus X-1 black hole, according to the latest research.

0.2 AU

Approximate distance between the black hole and its companion star - 20 per cent of the Earth-Sun distance.

800 times per second

The black hole's rotation period.

26 km

The black hole's Schwarzschild radius - the size of its event horizon or point of no return.

350,000 Suns

Approximate luminosity of the black hole's companion star.

30,000 km

Estimated diameter of the super-hot accretion disc around the Cygnus X-1 black hole.

Inside Cygnus X-1

How this binary system has been tearing itself apart in one of the most volatile stellar partnerships

Cygnus X-1's black hole is thought to be the remnant of a massive star that died in a supernova a few million years ago. This brilliant stellar explosion left behind a core so dense and massive that it collapsed beyond the point where any internal pressure could hold it up.

A tiny, impossibly dense point in space known as a singularity was formed, the gravity of which is so great that not even light can escape it. The singularity seals itself off from the external universe within a barrier called an event horizon, marking the last point from which light can overcome its gravity. It's the event horizon that forms the boundary of a black hole as we see it from the external universe – the more massive the singularity, the more powerful its gravity and the larger its event horizon.

So how does this object, that's barely visible, produce the powerful X-rays that make Cygnus X-1 stand out so much? The answer lies in its relationship with its companion star, HD 226868. This stellar monster, with a mass measured to be between 20 and 40 times that of the Sun, pumps out up to 400,000 times as much energy. As the radiation forces its way out from the star's core it causes the outer layers to swell up to 17 times the solar diameter, heating the surface to a searing blue-hot 31,000 degrees Celsius (56,000 degrees Fahrenheit).

HD 226868 is classed as a blue supergiant, but like all stars of its kind, it's losing mass rapidly – the high temperatures at its surface cause its outer layers to boil away into space, creating a powerful stellar wind. HD 226868 is thought to shed an entire Sun's worth of material every 400,000 years.

Based on the speed at which the two objects circle one another, astronomers estimate the black hole has a mass of about 14.8 Suns and orbits at only twice the visible star's radius. This is far enough away for the orbit to remain stable, but close enough for the black hole's gravity to distort its companion's shape into something like that of a teardrop. As the star spins on its axis with respect to Earth, we see different amounts of its surface and so its brightness appears to vary slightly.

The black hole's gravity isn't quite strong enough to pull material completely away from the star's outer layers (as happens in some other binary systems), but particles ejected into HD 226868's stellar wind are rapidly pulled towards the black hole on a spiral path. The falling material creates a flattened disc around the black hole and friction between gases moving at different speeds in various parts of the disc heats them to very high temperatures.

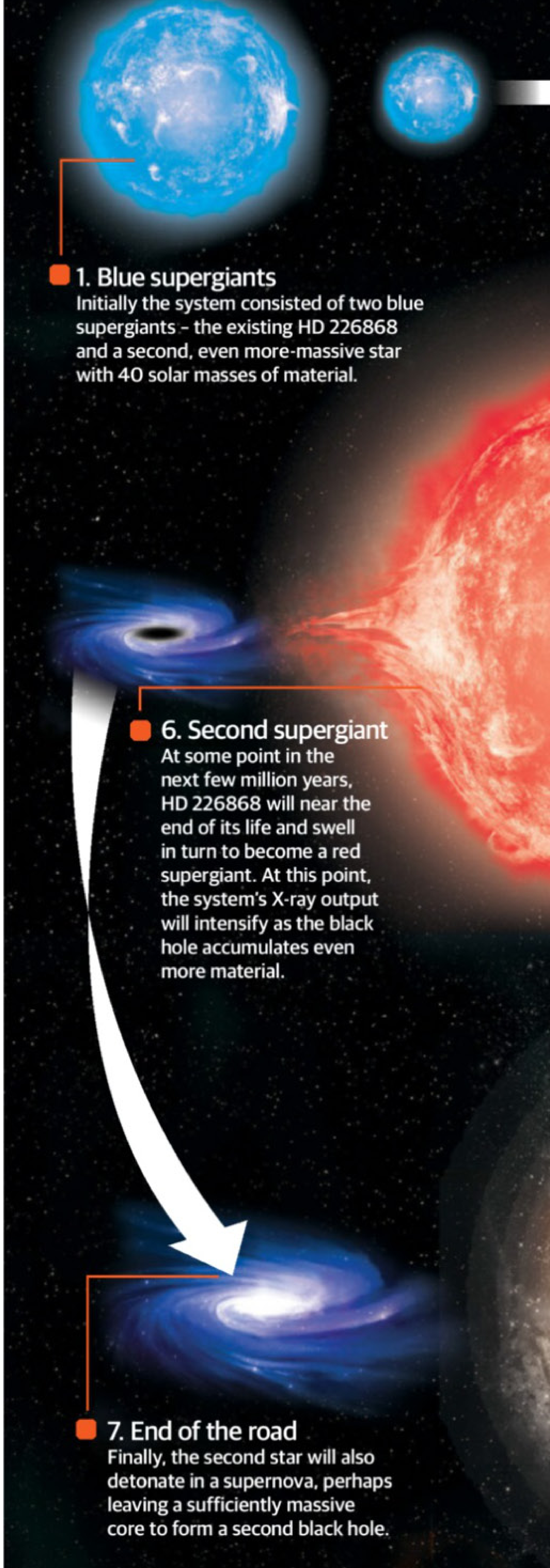
The innermost regions break down into an electrically charged gaseous plasma at more than 10 million degrees Celsius (18 million degrees Fahrenheit), emitting relatively long-wavelength, soft X-rays. These rays then gain additional energy through a process called Compton scattering, which involves individual photons of radiation interacting with electron particles moving at high speeds within a transparent corona above and below the thick disc. Ultimately this boosts the emitted photons to the hard X-ray part of the spectrum, giving Cygnus X-1 an effective temperature of more than a billion degrees.

Cygnus X-1's X-ray output flickers on a timescale of milliseconds as the amount of gas being fed into the central black hole varies. The output also goes through periodic dips with cycles of 5.6 days and 300 days. These dips seem to be caused by the X-ray disc's partial disappearance behind an intervening doughnut of gas around the supergiant, but the system also displays other patterns that aren't understood. In particular the corona that produces its hard X-rays sometimes disappears, leaving only the more-variable soft X-ray emission behind for scientists to eventually uncover. ■

> "As the radiation forces its way out from the star's core, it causes the outer layers to swell up to 17 times the solar diameter, heating the surface to a searing blue-hot 31,000 degrees"

Evolving system

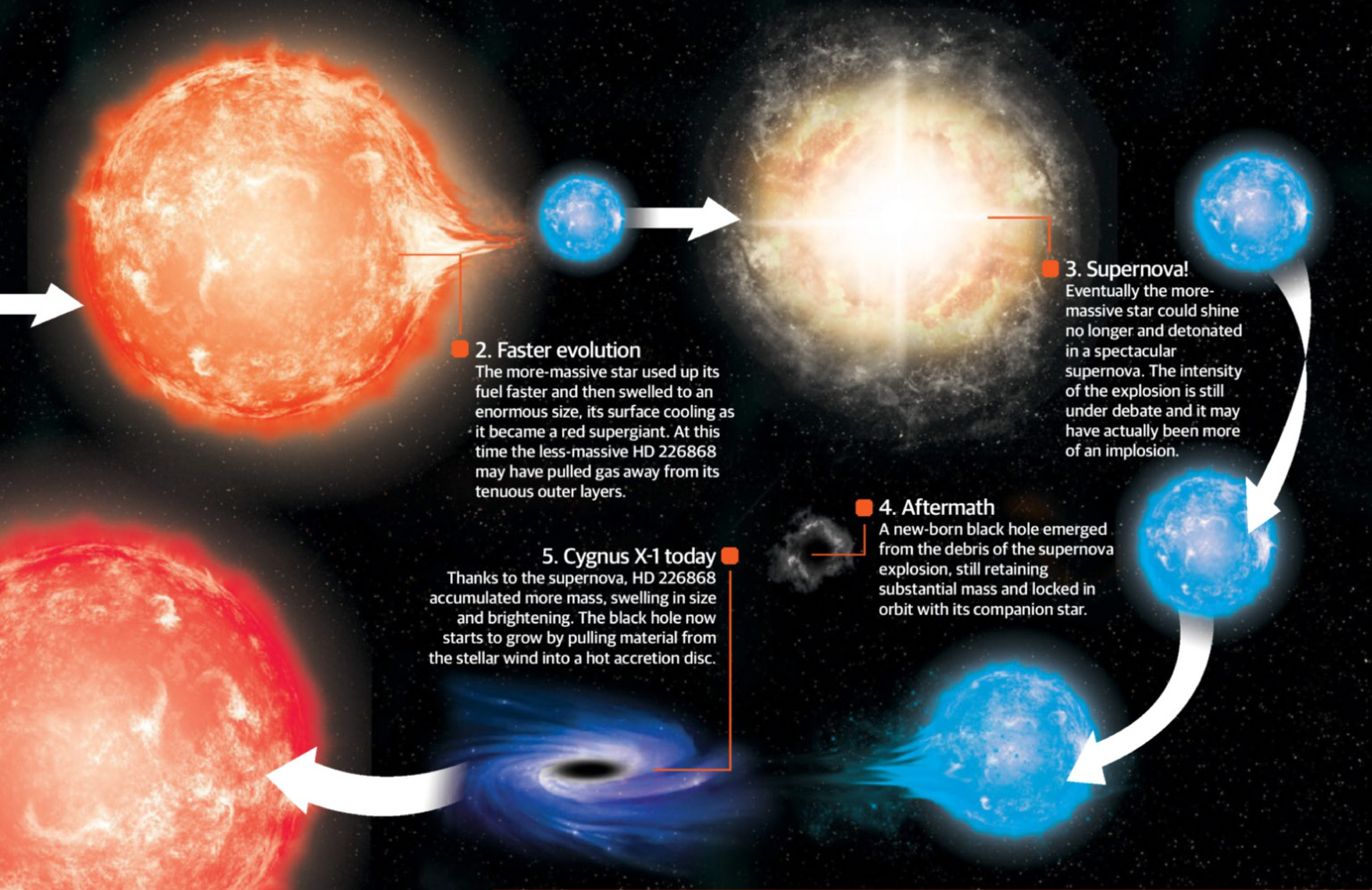
This sequence shows key stages in the past and future development of the unique Cygnus X-1 system



1. Blue supergiants
Initially the system consisted of two blue supergiants – the existing HD 226868 and a second, even more-massive star with 40 solar masses of material.

6. Second supergiant
At some point in the next few million years, HD 226868 will near the end of its life and swell in turn to become a red supergiant. At this point, the system's X-ray output will intensify as the black hole accumulates even more material.

7. End of the road
Finally, the second star will also detonate in a supernova, perhaps leaving a sufficiently massive core to form a second black hole.



2. Faster evolution

The more-massive star used up its fuel faster and then swelled to an enormous size, its surface cooling as it became a red supergiant. At this time the less-massive HD 226868 may have pulled gas away from its tenuous outer layers.

3. Supernova!

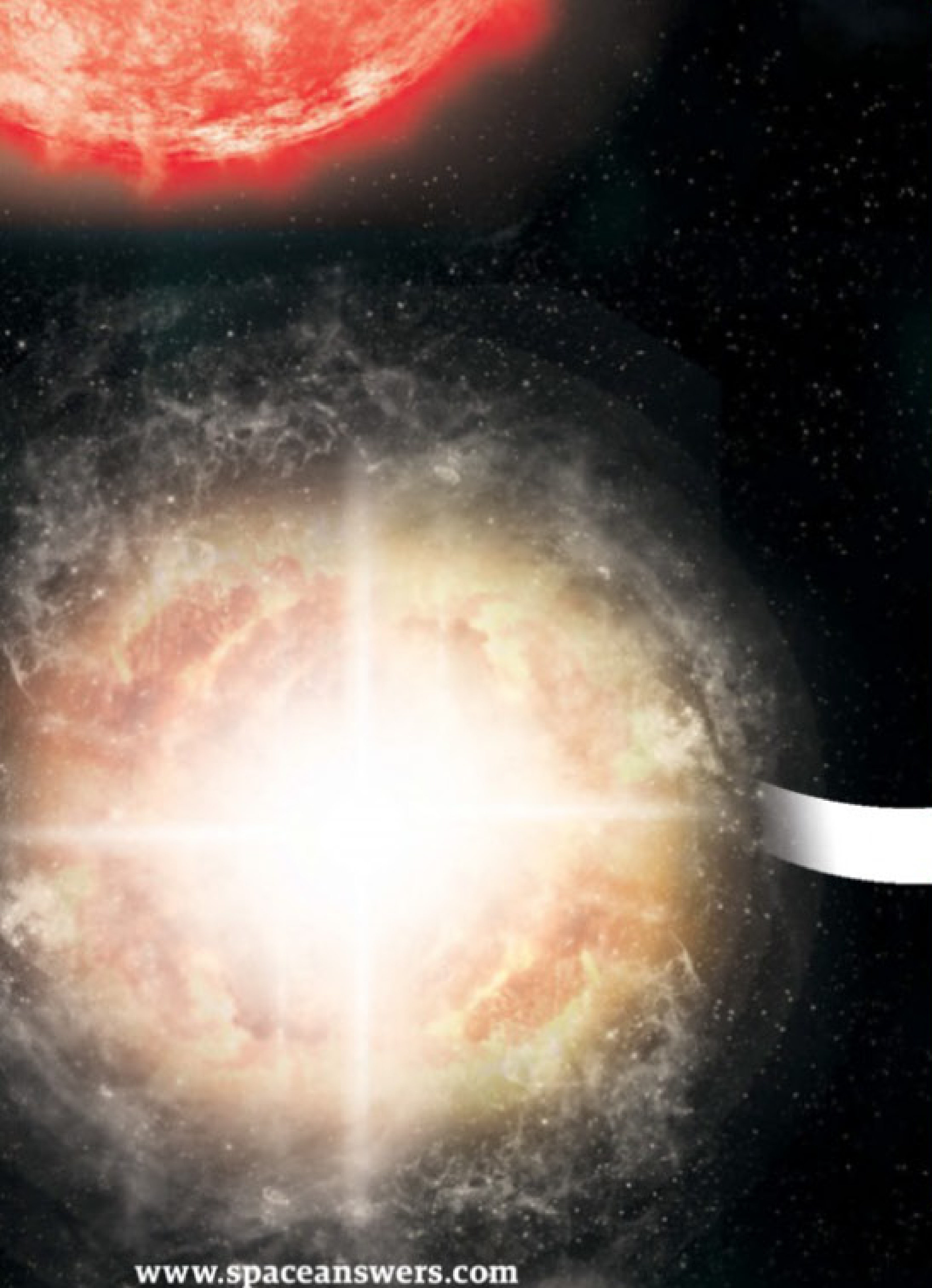
Eventually the more-massive star could shine no longer and detonated in a spectacular supernova. The intensity of the explosion is still under debate and it may have actually been more of an implosion.

4. Aftermath

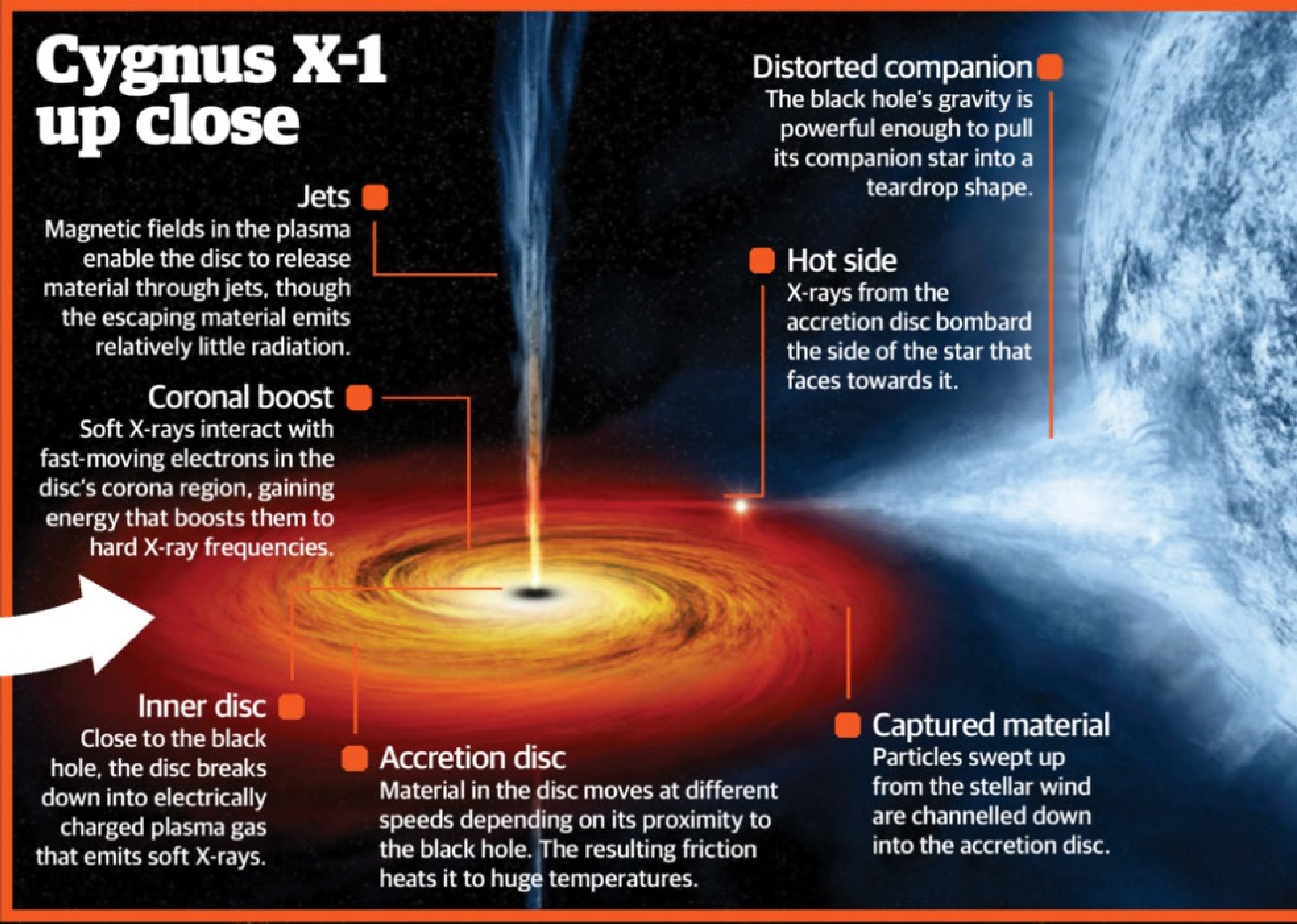
A new-born black hole emerged from the debris of the supernova explosion, still retaining substantial mass and locked in orbit with its companion star.

5. Cygnus X-1 today

Thanks to the supernova, HD 226868 accumulated more mass, swelling in size and brightening. The black hole now starts to grow by pulling material from the stellar wind into a hot accretion disc.



Cygnus X-1 up close



Jets

Magnetic fields in the plasma enable the disc to release material through jets, though the escaping material emits relatively little radiation.

Coronal boost

Soft X-rays interact with fast-moving electrons in the disc's corona region, gaining energy that boosts them to hard X-ray frequencies.

Inner disc

Close to the black hole, the disc breaks down into electrically charged plasma gas that emits soft X-rays.

Accretion disc

Material in the disc moves at different speeds depending on its proximity to the black hole. The resulting friction heats it to huge temperatures.

Distorted companion

The black hole's gravity is powerful enough to pull its companion star into a teardrop shape.

Hot side

X-rays from the accretion disc bombard the side of the star that faces towards it.

Captured material

Particles swept up from the stellar wind are channelled down into the accretion disc.

Observing a black hole

Studying an object that lets no light escape is as tricky as it sounds, but innovative telescopes have unlocked unseen layers of space

As the nearest known black hole to Earth, Cygnus X-1 has been subjected to intensive study over five decades. Most of what we know has come from satellite-based observatories and particularly orbiting X-ray telescopes. The system is usually the brightest source of hard X-rays in the sky, but generating images from these presents unique challenges. For a start they're extremely hard to focus on, as when they hit a reflecting surface head-on, they tend to either be absorbed or pass straight through it.

Early X-ray astronomy satellites had very low directional resolution – in principle they consisted of a shielded X-ray detector with an open window at one end, so attempts to map the X-ray sky involved scanning and recording the directions from which X-rays entered the detector window.

Fortunately more-recent orbiting telescopes have transformed our view of the X-ray sky. Beginning with the German-led ROSAT satellite (launched in 1990), increasing use has been made of an instrument design first outlined in the 1950s by physicist Hans Wolter. These telescopes use conical metal mirrors whose surfaces lie at fairly shallow angles to the incoming radiation, creating a situation in which X-rays ricochet off the surface and are deflected towards a focus point. By using several sets of concentric mirrors nested within one another, it's possible to form an image of a moderately large area of the sky, which can then be recorded using a solid-state detector fairly similar to the CCDs used in visible-light cameras.

The latest and most-sophisticated X-ray instruments to turn their attention towards Cygnus X-1 are NASA's Chandra X-ray Observatory and the European Space Agency's XMM-Newton (X-ray Multi-Mirror) spacecraft. Both were launched in 1999 and are still operational after a decade and a half in orbit. Chandra has a single telescope assembly using four pairs of nested mirrors to focus X-rays from a small part of the sky at high resolution. XMM-Newton, in contrast, uses no fewer than three separate telescopes with 58 individual mirrors in each to focus X-rays with a variety of different wavelengths, imaging larger areas of the sky than Chandra at lower resolution. Both telescopes also carry spectrometers capable of splitting and analysing X-rays from individual objects according to their energies.

Using observations from Chandra, XMM-Newton and other telescopes, in 2011 astronomers produced the most detailed analysis of the Cygnus X-1 system yet. Radio telescope measurements first pin-pointed the system's position in the sky as seen from opposite sides of Earth's orbit. The slight difference caused by our shifting point of view (an effect called parallax) was used to calculate the system's distance with unprecedented precision, putting it 6,070 light years from Earth. Combined with the optical spectroscopy of the companion star, this enabled researchers to determine that the black hole's mass at 14.8 times the Sun's, and that it moves through its region of space at a fairly sedate speed of about nine kilometres (5.6 miles) per second.

Finally, X-ray studies confirmed the general structure of the system and determined the black hole's rotation rate with unprecedented accuracy, revealing that it spins roughly 800 times a second – close to the maximum theoretical limit.

The sudden loss of mass associated with a traditional supernova explosion has a tendency to give binary systems a kick that throws them across space at high speed and also tends to reduce the speed with which the collapsed stellar core rotates. Cygnus X-1's combination of rapid rotation and slow speed through space suggest it may have formed in another way – a stellar implosion, rather than a true supernova explosion, in which the collapsing black hole simply consumed its progenitor star from within.

If the black hole really did form in this way, it would be the first confirmed example of this kind of highly unusual stellar cataclysm and yet another reason to study the system. Whatever the truth, it seems certain that, five decades on from its discovery and after being the subject of more than a thousand scientific papers, Cygnus' most famous object isn't ready for its swan song just yet. ●

XMM-NEWTON

Solar panels
The fully extended solar panels give the spacecraft a wingspan of 16 metres (52.5 feet).

Front aperture
X-rays enter the three separate telescopes and are bent towards a focus at varying distances along the spacecraft's interior.

Mission profile

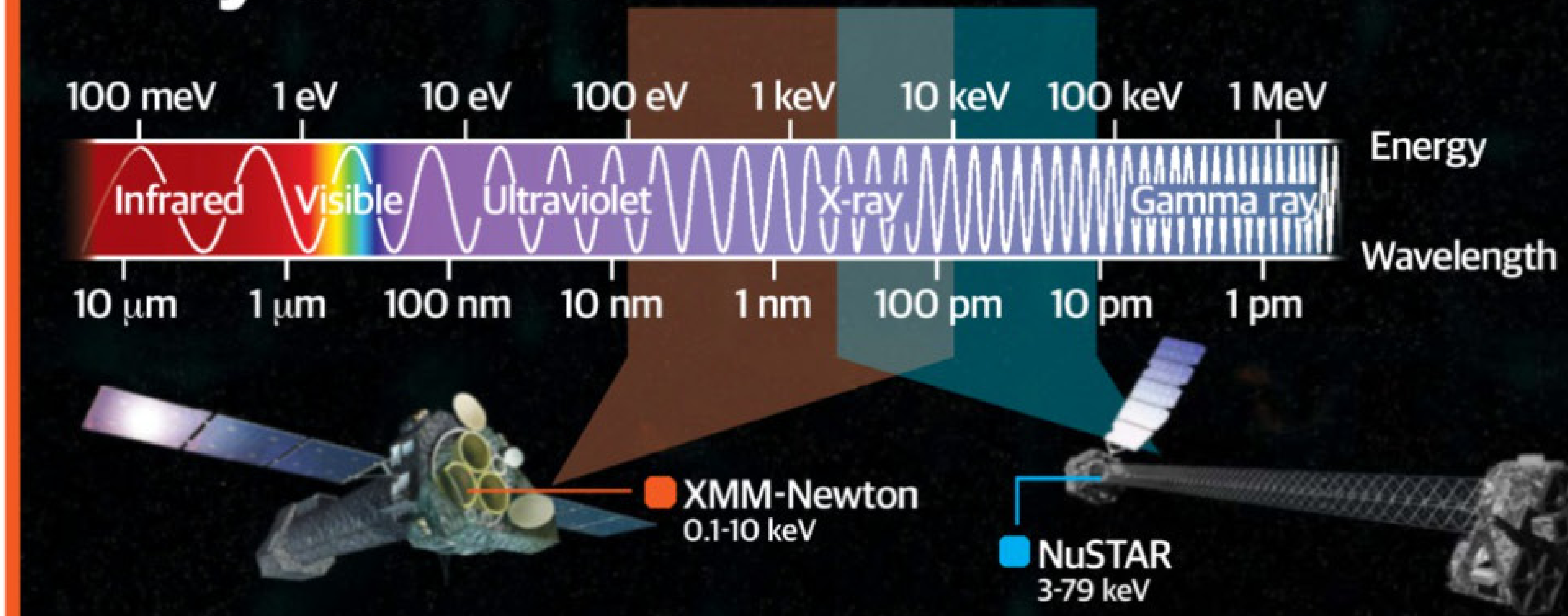
XMM-NEWTON

Launch: 10 December 1999
Launch vehicle: Ariane 5
Mass: 3,800kg (8,380lbs)
Length: 10m (33ft)
Orbit type: Elliptical, 7,000-114,000km (4,350-71,000 miles) from Earth.
Earliest deorbit date: Unknown

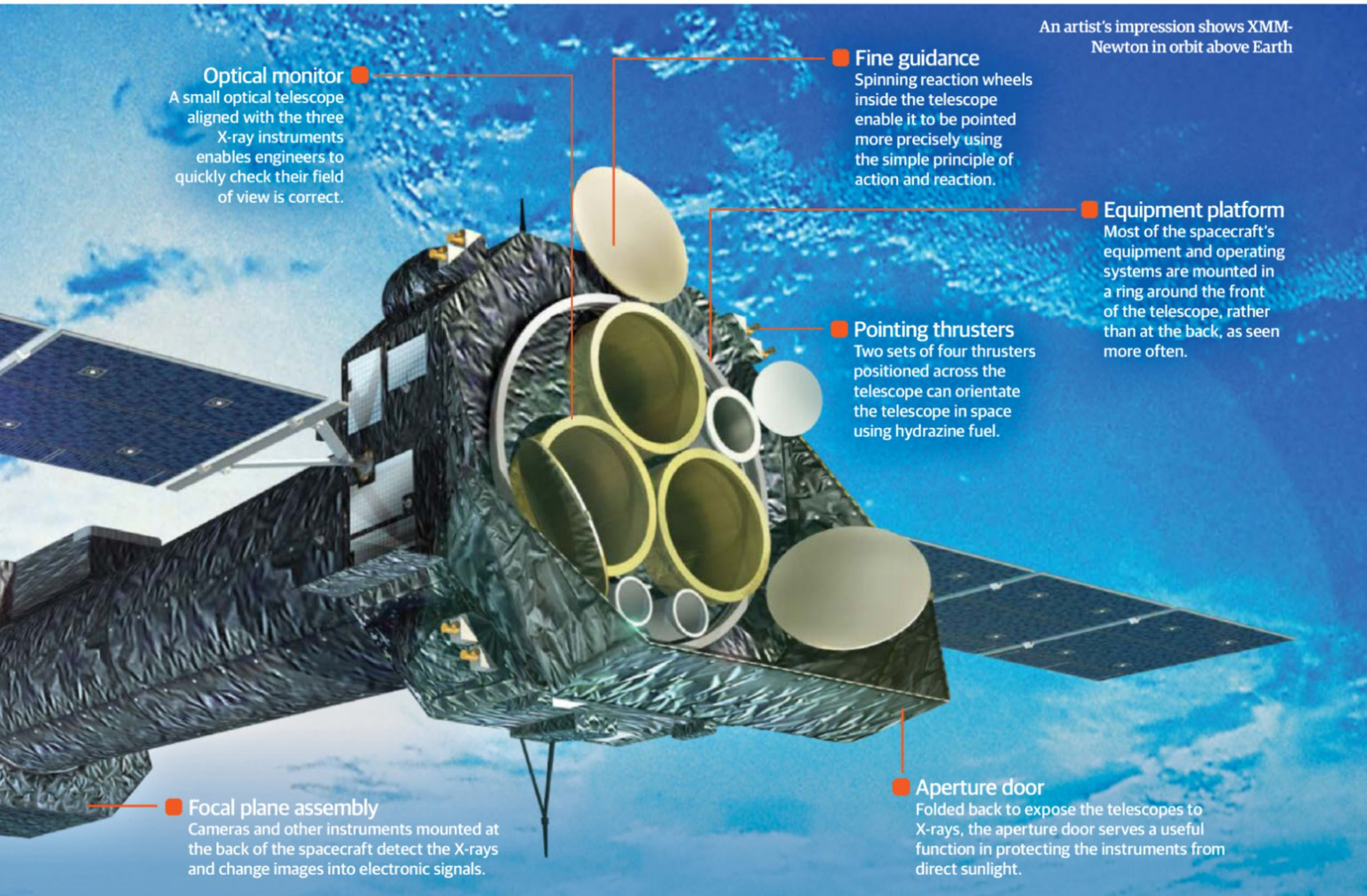
XMM-Newton's key discoveries include X-ray emissions used to identify some of the most distant galaxy clusters known, information about a host of extreme binary systems such as Cygnus X-1 and so-far-unexplained new sources of X-rays in far-off space.

XMM-Newton undergoes testing at the European Space Research and Technology Center in the Netherlands

X-ray detection



X-ray wavelengths range from around ten nanometres at their longest, down to just ten picometres (1,000 times shorter) at their shortest. The shorter the wavelength of an X-ray photon, the more energy it packs in and X-ray energies range from 100 electronvolts (eV) up to 100 kiloelectronvolts (keV) – the standard units of energy measurement in everyday situations. XMM-Newton images X-rays with energies of up to ten keV, covering all soft X-rays and many hard X-rays. NASA's NuSTAR telescope was built to detect even the higher energies associated with phenomena such as supermassive black holes – monsters millions of times more massive than Cygnus X-1.



An artist's impression shows XMM-Newton in orbit above Earth

Optical monitor
A small optical telescope aligned with the three X-ray instruments enables engineers to quickly check their field of view is correct.

Fine guidance
Spinning reaction wheels inside the telescope enable it to be pointed more precisely using the simple principle of action and reaction.

Equipment platform
Most of the spacecraft's equipment and operating systems are mounted in a ring around the front of the telescope, rather than at the back, as seen more often.

Pointing thrusters
Two sets of four thrusters positioned across the telescope can orientate the telescope in space using hydrazine fuel.

Focal plane assembly
Cameras and other instruments mounted at the back of the spacecraft detect the X-rays and change images into electronic signals.

Aperture door
Folded back to expose the telescopes to X-rays, the aperture door serves a useful function in protecting the instruments from direct sunlight.

Up close with a monster

A new project hopes to teach us more about black holes by uniting telescopes around the world

Cygnus X-1 might be the nearest black hole and the first to be discovered, but it's no longer the most famous – that title goes to Sagittarius A*, a supermassive black hole with the mass of over 4 million Suns that lies at the centre of our galaxy.

First hypothesised in the early 1970s, this black hole behemoth's existence was confirmed in 2002 when astronomers measured nearby stars orbiting it at high speed. While stellar-mass black holes typically have event horizons just a few tens of kilometres across, Sagittarius A* is many times the size of the Sun. This means that, even across a distance of 26,000 light years, it offers our best hope for observing a black hole directly.

Unfortunately this supermassive singularity long ago swept the region of space around it clear of substantial material, so while it can certainly emit X-rays when occasional debris strays into its path, at the moment it remains frustratingly placid. The only radiation coming from the region takes the form of infrared and radio waves produced as small amounts of gas sift gently into the black hole.

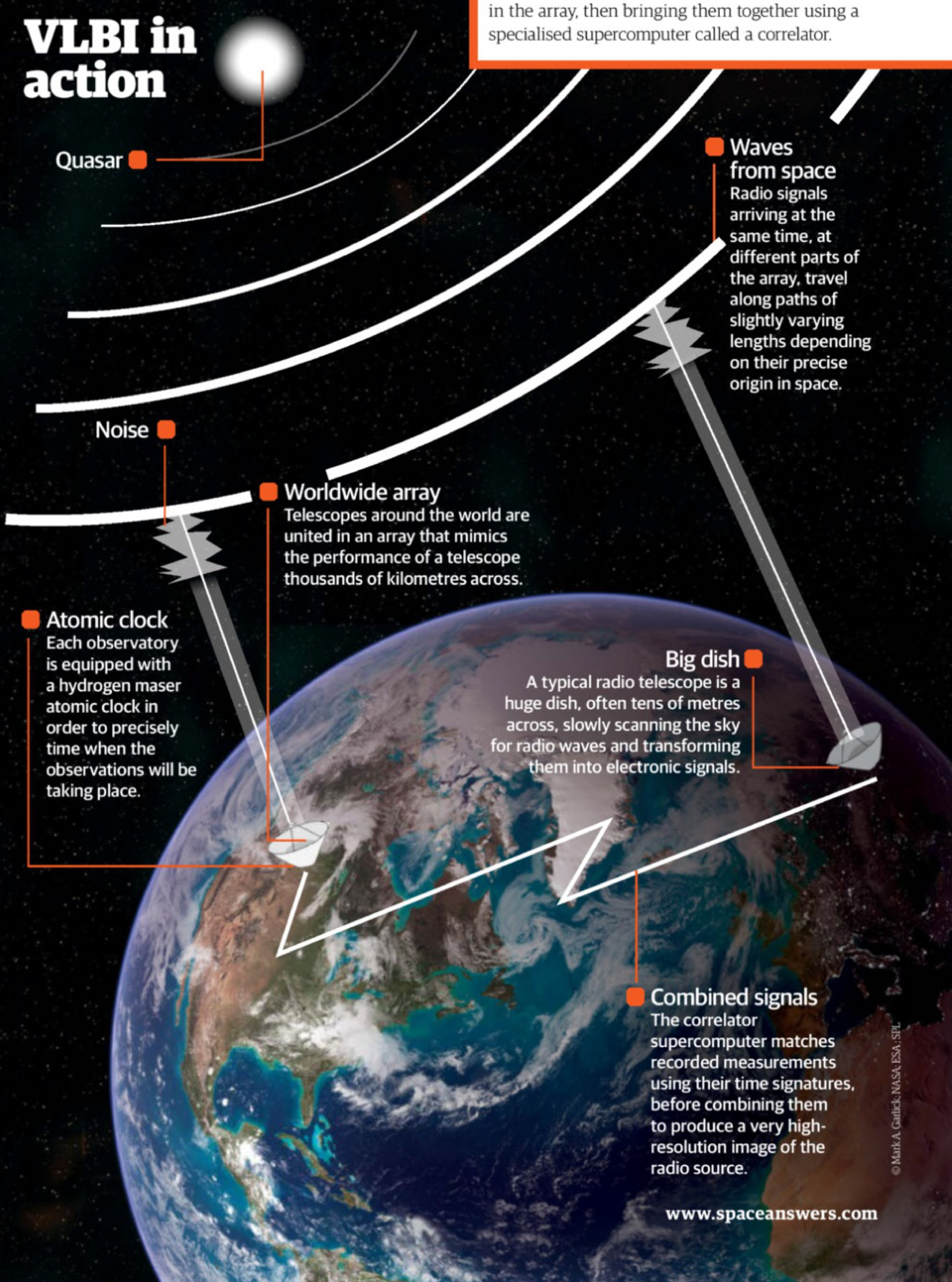
These long-wavelength rays present a huge challenge to astronomers trying to see the intricate details of Sagittarius A*. For a given diameter of telescope, they produce much lower-resolution images than visible light or X-rays, so the only solution is to go big. For an object as small and distant as this, that means a telescope the size of the Earth. The Event Horizon Telescope (EHT) is an international project aimed at linking existing radio telescopes around the world into a huge array with the power to resolve objects down to the apparent diameter of an orange on the surface of the Moon. The team behind it hopes to detect phenomena such as the predicted shadow created as radiation is deflected by the black hole's gravity. If they succeed, they may be able to extend the technique into space, targeting far smaller objects like Cygnus X-1.

The precise shape of the black hole's shadow will answer questions about its properties and whether it strictly obeys the predictions of general relativity

The Event Horizon Telescope

The EHT will make use of a technique known as Very Long Baseline Interferometry (VLBI). This involves making precisely synchronised observations of the same object from widely separated telescopes: radio waves will have had to travel slightly different distances to reach each of the different observatories. By measuring the differences in the length of their paths, it's possible to synthesise an image with the level of detail that would be achieved by an enormous telescope. In practise, this form of VLBI is achieved by recording simultaneous observations at all the telescopes in the array, then bringing them together using a specialised supercomputer called a correlator.

VLBI in action



Quasar

Noise

Waves from space
Radio signals arriving at the same time, at different parts of the array, travel along paths of slightly varying lengths depending on their precise origin in space.

Worldwide array
Telescopes around the world are united in an array that mimics the performance of a telescope thousands of kilometres across.

Atomic clock
Each observatory is equipped with a hydrogen maser atomic clock in order to precisely time when the observations will be taking place.

Big dish
A typical radio telescope is a huge dish, often tens of metres across, slowly scanning the sky for radio waves and transforming them into electronic signals.

Combined signals
The correlator supercomputer matches recorded measurements using their time signatures, before combining them to produce a very high-resolution image of the radio source.

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BUILT FOR ADVENTURE

HAWK
T100

SUPERLIGHT
POLYCARBONATE CASE

T100 GTLS
SELF - POWERED
ILLUMINATION

IN THE PHOTO:
Camping underneath the Aurora Borealis,
Iceland. Captured by Tim Nunn.

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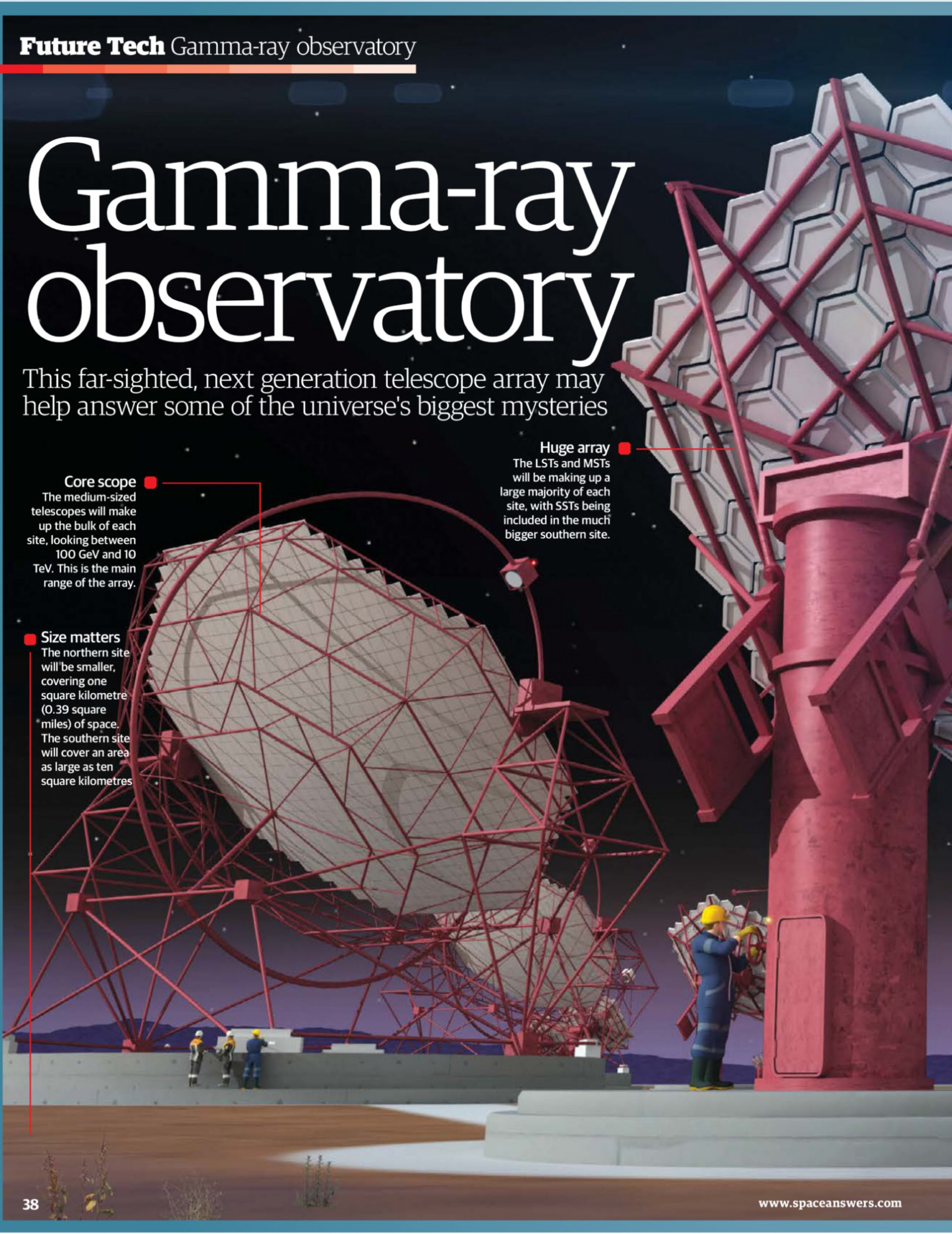
Gamma-ray observatory

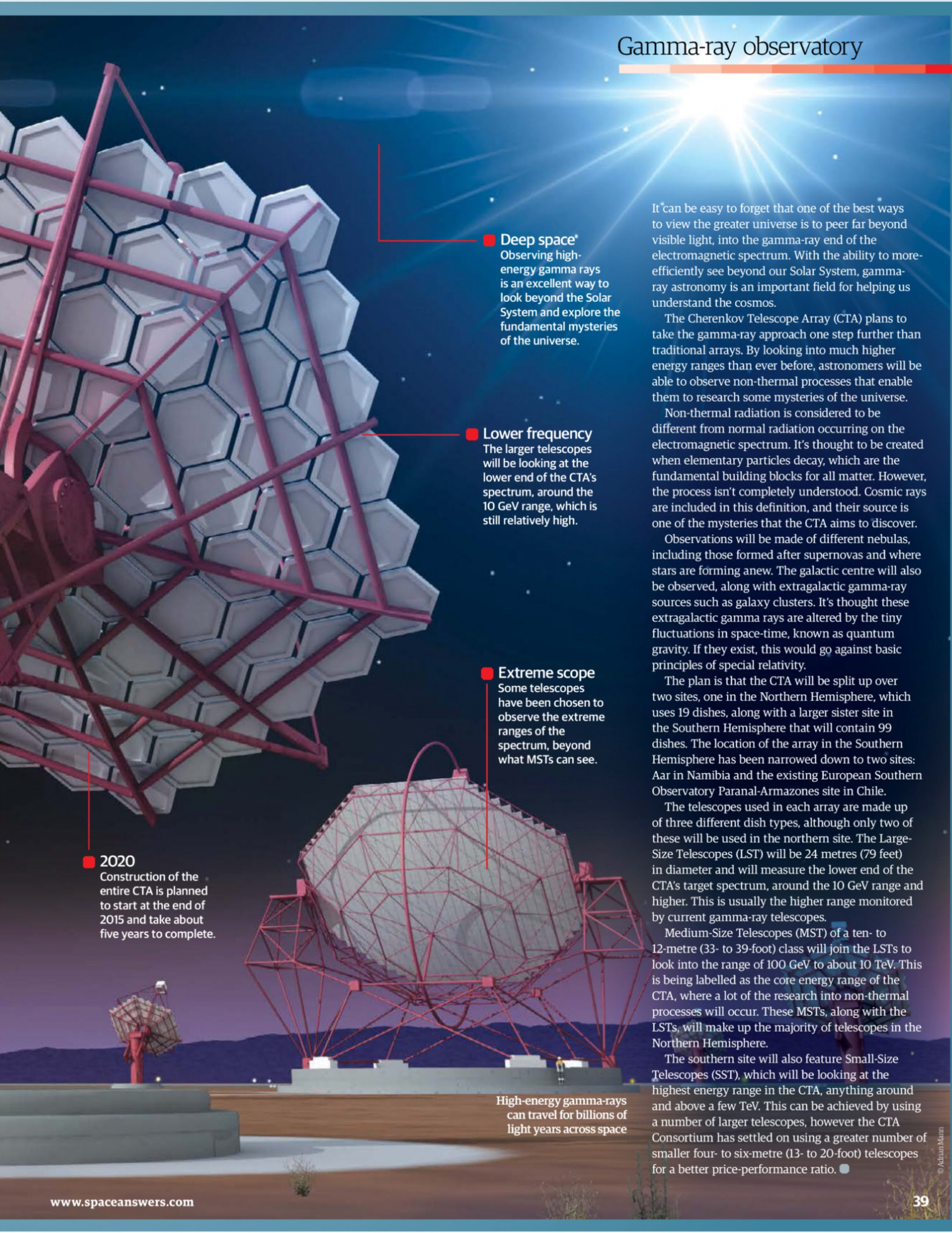
This far-sighted, next generation telescope array may help answer some of the universe's biggest mysteries



Huge array
The LSTs and MSTs will be making up a large majority of each site, with SSTs being included in the much bigger southern site.

Core scope
The medium-sized telescopes will make up the bulk of each site, looking between 100 GeV and 10 TeV. This is the main range of the array.

Size matters
The northern site will be smaller, covering one square kilometre (0.39 square miles) of space. The southern site will cover an area as large as ten square kilometres



Deep space
Observing high-energy gamma rays is an excellent way to look beyond the Solar System and explore the fundamental mysteries of the universe.

Lower frequency
The larger telescopes will be looking at the lower end of the CTA's spectrum, around the 10 GeV range, which is still relatively high.

Extreme scope
Some telescopes have been chosen to observe the extreme ranges of the spectrum, beyond what MSTs can see.

2020
Construction of the entire CTA is planned to start at the end of 2015 and take about five years to complete.

High-energy gamma-rays can travel for billions of light years across space

© Adrian Mann

It can be easy to forget that one of the best ways to view the greater universe is to peer far beyond visible light, into the gamma-ray end of the electromagnetic spectrum. With the ability to more-efficiently see beyond our Solar System, gamma-ray astronomy is an important field for helping us understand the cosmos.

The Cherenkov Telescope Array (CTA) plans to take the gamma-ray approach one step further than traditional arrays. By looking into much higher energy ranges than ever before, astronomers will be able to observe non-thermal processes that enable them to research some mysteries of the universe.

Non-thermal radiation is considered to be different from normal radiation occurring on the electromagnetic spectrum. It's thought to be created when elementary particles decay, which are the fundamental building blocks for all matter. However, the process isn't completely understood. Cosmic rays are included in this definition, and their source is one of the mysteries that the CTA aims to discover.

Observations will be made of different nebulas, including those formed after supernovas and where stars are forming anew. The galactic centre will also be observed, along with extragalactic gamma-ray sources such as galaxy clusters. It's thought these extragalactic gamma rays are altered by the tiny fluctuations in space-time, known as quantum gravity. If they exist, this would go against basic principles of special relativity.

The plan is that the CTA will be split up over two sites, one in the Northern Hemisphere, which uses 19 dishes, along with a larger sister site in the Southern Hemisphere that will contain 99 dishes. The location of the array in the Southern Hemisphere has been narrowed down to two sites: Aar in Namibia and the existing European Southern Observatory Paranal-Armazones site in Chile.

The telescopes used in each array are made up of three different dish types, although only two of these will be used in the northern site. The Large-Size Telescopes (LST) will be 24 metres (79 feet) in diameter and will measure the lower end of the CTA's target spectrum, around the 10 GeV range and higher. This is usually the higher range monitored by current gamma-ray telescopes.

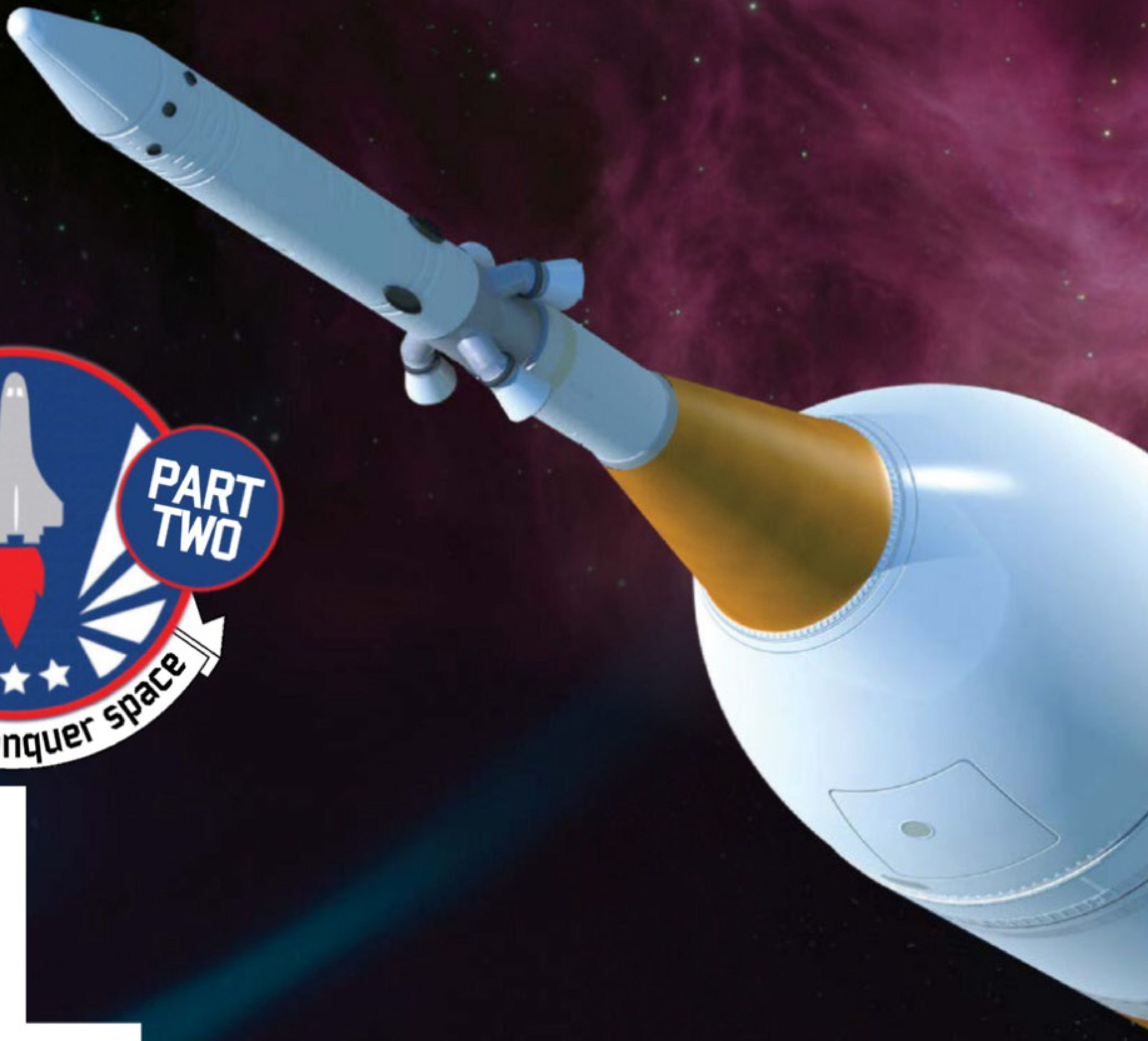
Medium-Size Telescopes (MST) of a ten- to 12-metre (33- to 39-foot) class will join the LSTs to look into the range of 100 GeV to about 10 TeV. This is being labelled as the core energy range of the CTA, where a lot of the research into non-thermal processes will occur. These MSTs, along with the LSTs, will make up the majority of telescopes in the Northern Hemisphere.

The southern site will also feature Small-Size Telescopes (SST), which will be looking at the highest energy range in the CTA, anything around and above a few TeV. This can be achieved by using a number of larger telescopes, however the CTA Consortium has settled on using a greater number of smaller four- to six-metre (13- to 20-foot) telescopes for a better price-performance ratio.

10 VITAL SPACE MISSIONS

PART TWO

Quest to conquer space



Four different space agencies are pulling together to fill in our map of the Solar System with the most ambitious deep-space missions yet!

Written by Luis Villazon

We went to the Moon not because it's easy, but because it's hard. Our mission since that auspicious day in 1969 has been to send astronauts to destinations beyond the Earth-Moon system. So to a casual observer, it may seem that we peaked too soon and that now, we've stalled in our progress.

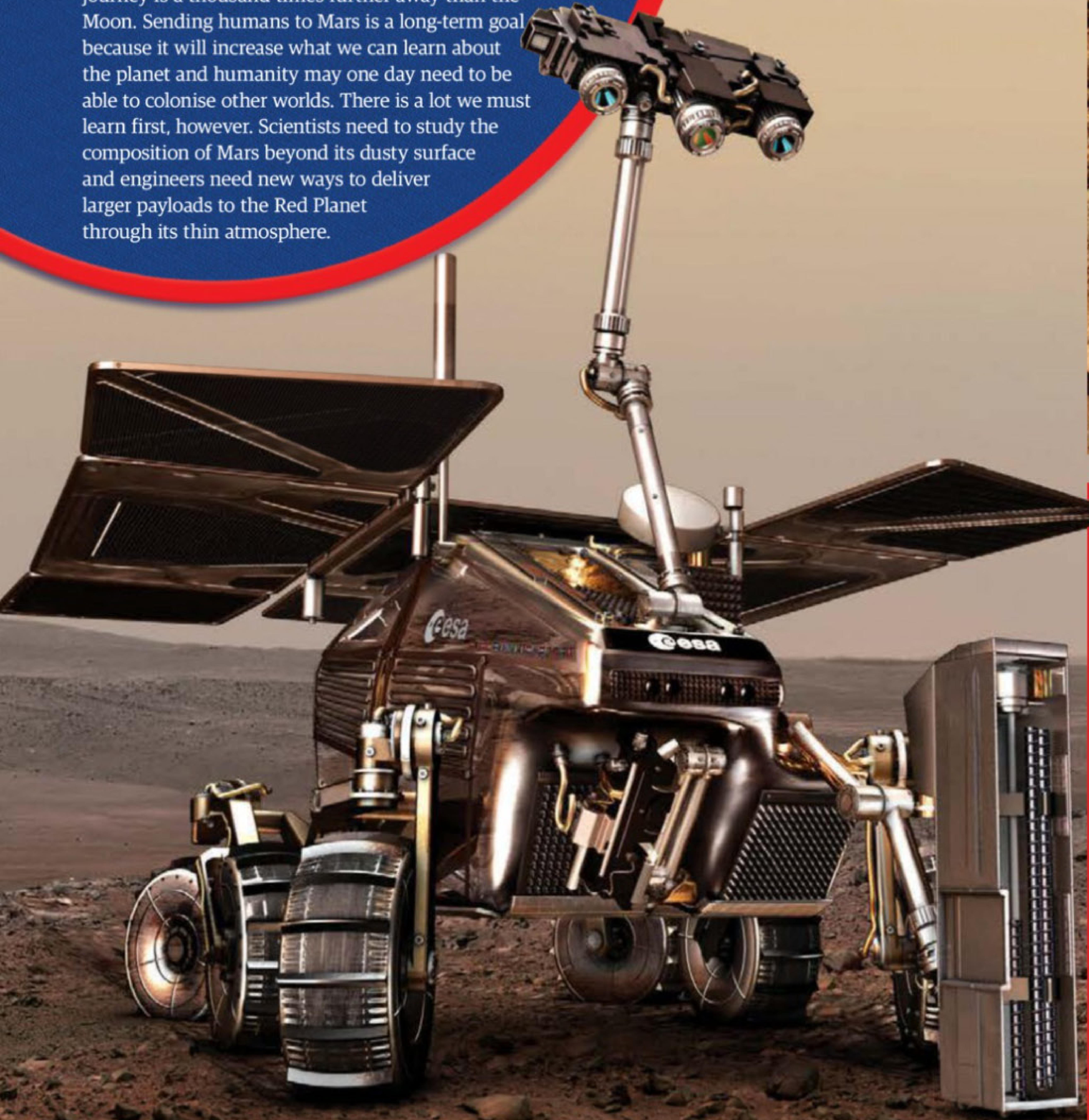
Since Mariner 2 flew past Venus in 1962, there has been a steady stream of unmanned spacecraft launched to most of the planets in our Solar System. However, we've never orbited any of the moons of Jupiter, never landed on a comet and no probes have yet reached Pluto. Even Mars, the planet we know most about after our own, still has yet to answer the most important question – did it ever harbour life?

In the last decade, space has become more accessible to private ventures, as prohibitively expensive technology has come down in price. No longer the exclusive domain of a government agency, mission proposals from tycoons, business-savvy space experts and ex-NASA employees have raised the bar, making the future of space exploration an altogether more-fascinating industry to watch unfurl.

Here are ten of the most exciting missions designed to dramatically push the boundaries of our knowledge and launch a new era of discovery.

Exploring Mars

Mars is our nearest neighbour and the only planet currently feasible to consider for manned missions, but this won't be just a red-coloured repeat of the Moon landings. Mars has twice the gravity and the journey is a thousand times further away than the Moon. Sending humans to Mars is a long-term goal because it will increase what we can learn about the planet and humanity may one day need to be able to colonise other worlds. There is a lot we must learn first, however. Scientists need to study the composition of Mars beyond its dusty surface and engineers need new ways to deliver larger payloads to the Red Planet through its thin atmosphere.



The Rover's drill extends in four sections to drill two metres (6.6 feet) into the Martian subsoil. This is where water is most likely to be found and, with it, life

The surface of Mars isn't the most forgiving of terrains

1 Exploring the surface

ExoMars is a complex project involving four spacecraft sent on two separate launches. The first lifts off in January 2016 carrying the Trace Gas Orbiter (TGO) and a stationary lander called Schiaparelli. When they reach Mars in October of that year, Schiaparelli will separate and attempt an audacious landing during the Martian dust storm season. It will use a heat shield, then a supersonic parachute and pulse-fired liquid-fuel engines, before free-falling the last metre (3.3 feet) onto a crumple-zone structure. If it survives this ordeal, it will have enough batteries for up to eight days of operation, measuring wind speed and the electrical charge in the dust storms.

The TGO will use aerobraking to lower its orbit to 400 kilometres (249 miles), scanning the atmosphere for methane and the ground for subsurface water. After two years it will lower its orbit in time to provide a communications relay for the craft delivered by the second launch. This will be a 1,800-kilogram (1,764-pound) lander, including the 310-kilogram (683-pound) ExoMars rover equipped with scientific instruments a drill capable of taking samples from as deep as two metres (6.6 feet).

Dangerous driving

Paolo Bellutta, Mars Exploration Rover driver, JPL

What is it like to drive a Mars rover?
It's mostly an exercise in patience. We need to prepare a sequence of commands that get sent to Mars as one batch and executed by the vehicle. We typically hear from the rovers once per Martian day.

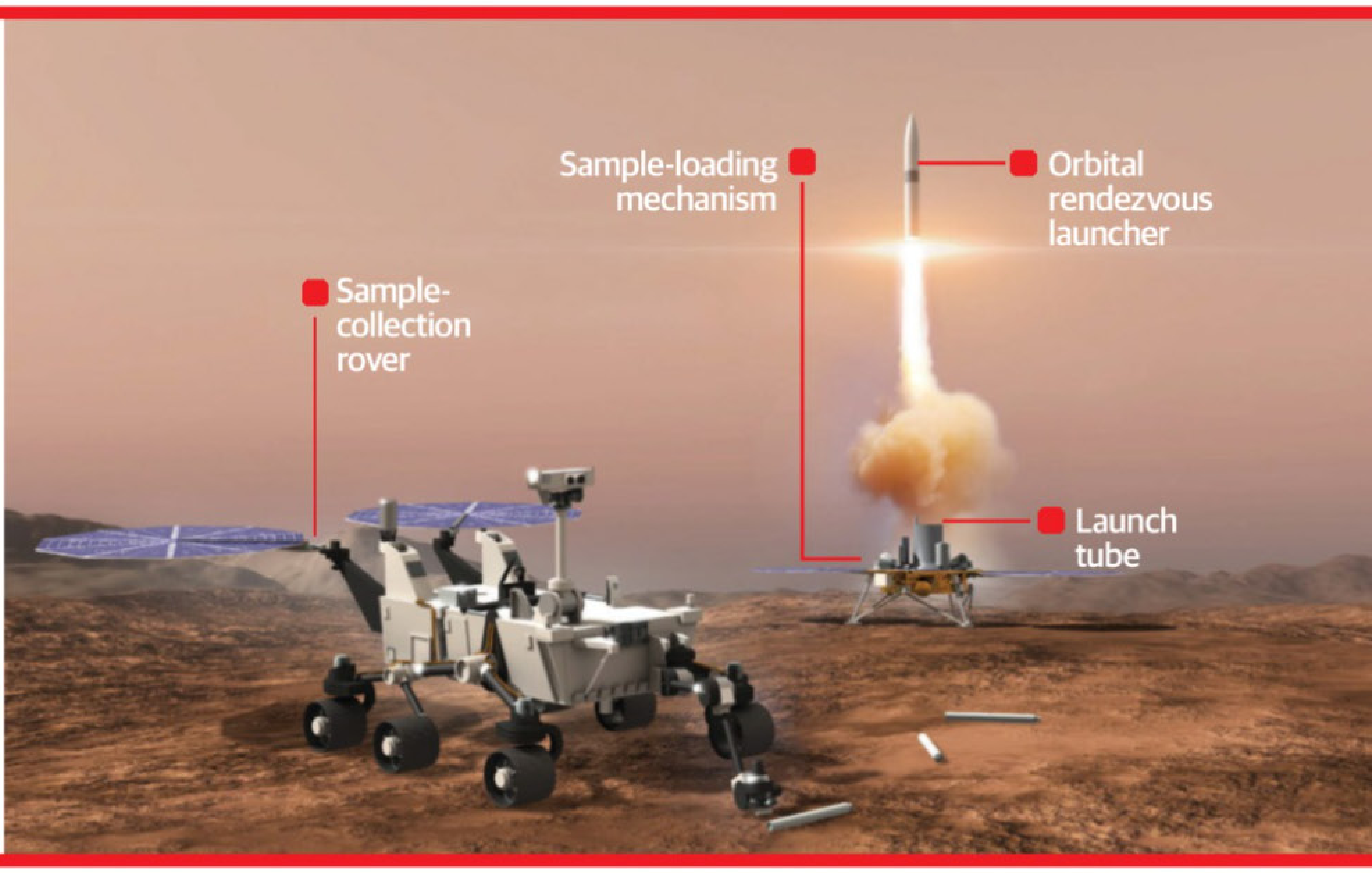
What happens if the rover gets stuck on a piece of terrain?
Since there is no roadside assistance on Mars, we have to figure out means to manoeuvre around obstacles or difficult terrain. Sometimes we have to replicate the terrain type we have on Mars and experiment [with replica rovers] until we find a solution.

Why do the rovers have to travel so slowly on the surface?
To drive faster we would need bigger motors, larger and heavier batteries, thicker cables, more-complex electronics and more-powerful computers. Also, it's already quite difficult to drive on Mars at our top speed of 0.16 kilometres (0.1 miles) per hour. It would be even more frightening to drive faster!

2 Sample return

Bringing a physical sample of Martian soil back to Earth labs vastly increases the number of tests we can perform on it, but it's a lot harder to do. NASA, the European Space Agency (ESA), Russia and China have sample-return missions planned, but aren't likely to launch before 2020.

The most innovative of these missions is a NASA plan to send a spacecraft that uses up all its fuel during the landing, but then refuels itself from CO2 in the Martian atmosphere and water in the soil. Water can be split using electricity to produce hydrogen and oxygen. The hydrogen can then be reacted with CO2 by a process known as the Sabatier reaction to produce methane. The lander would spend 18 months slowly manufacturing enough fuel to refill its tanks, while shoebox-sized rovers collect soil samples and load them for transport. The Mars Ascent Vehicle will only have enough fuel to put itself back into orbit around Mars. It will then make a rendezvous with an orbiter that will collect it for the long trip home.



3 Manned landing

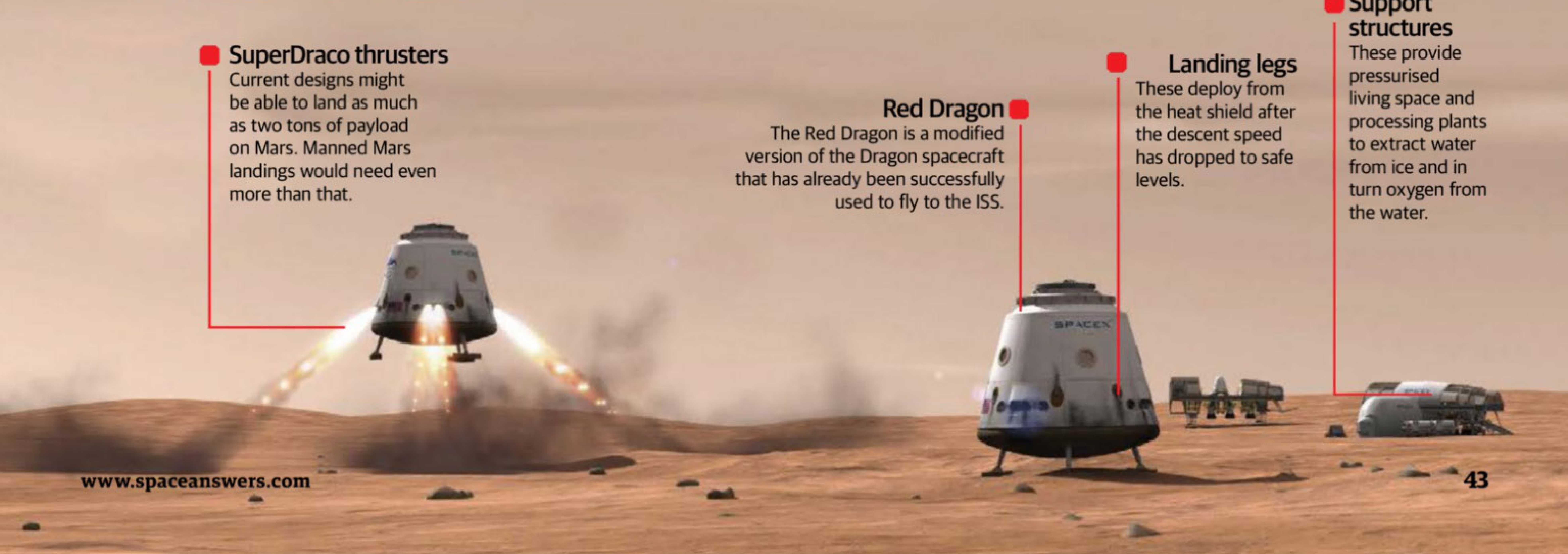
If returning a 500-gram (18-ounce) sample of soil from Mars is hard, sending humans must surely rank as almost impossible. Yet both NASA and private companies are actively working towards pulling it off by the 2030s and for a lot less than the £600 billion ($1 trillion) figure that is sometimes bandied about.

NASA's plans involve using the SLS heavy launch rocket to lift a Mars spacecraft in sections and assemble it in orbit. The SLS isn't scheduled to begin flight tests before 2017 and a Mars mission would probably need at least seven launches to build the spacecraft and lift the supplies. One way to save fuel (and therefore reduce launch mass) might be to use solar electric propulsion (SEP), also known as ion drives, to send fuel and supplies slower and far ahead of the time they are needed.

Once a manned mission reaches Mars, actually landing safely is an even bigger challenge. The best entry, descent and landing (EDL) technology currently available can cope with a payload of no more than a ton. That's what the Mars Curiosity rover massed, but a capsule capable of transporting humans and keeping them alive on the surface will be much heavier. It's not simply a question of using bigger parachutes – the thin atmosphere of Mars doesn't enable large chutes to fully open. Braking rockets will be essential, but firing up rocket motors while travelling at supersonic velocities through the atmosphere is like lighting a match in a hurricane. This is where private companies may be able to lend a hand. SpaceX is planning to use a modified version of its Dragon Spacecraft, while experience gained with restarting the engines of its reusable Falcon 9 booster will help refine the technology in the SuperDraco thrusters used by Dragon.

> "The thin atmosphere of Mars doesn't enable large chutes to fully open"

Will SpaceX land the first man on Mars?



SuperDraco thrusters
Current designs might be able to land as much as two tons of payload on Mars. Manned Mars landings would need even more than that.

Red Dragon
The Red Dragon is a modified version of the Dragon spacecraft that has already been successfully used to fly to the ISS.

Landing legs
These deploy from the heat shield after the descent speed has dropped to safe levels.

Support structures
These provide pressurised living space and processing plants to extract water from ice and in turn oxygen from the water.

Asteroids and comets

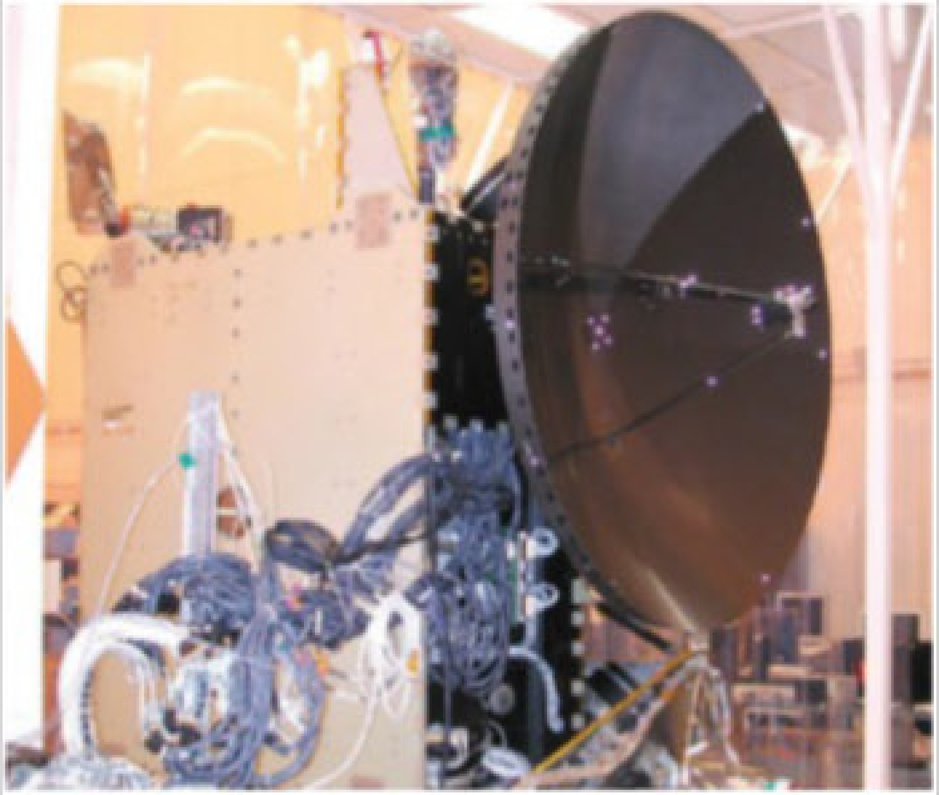
Asteroids and comets are made of the same material that originally clumped into planets. Because they haven't been subjected to the same heating and stresses, they have changed much less. Most asteroids lie in a belt between the orbits of Mars and Jupiter – a thin rubble field left over from the impact of ancient protoplanets. Comets come from the edge of the Solar System and still have a lot of their water and volatile compounds, streaming plumes of dust and gas as their orbits bring them close to the Sun.

4 Dwarf planet encounter

Dawn was launched seven years ago and has been patiently making its way towards Ceres, the largest body in the Asteroid Belt, ever since. Its engines are among the least powerful ever flown and yet it can reach over ten kilometres (6.2 miles) per second of velocity change (delta-V) – more than any other spacecraft. This is because it uses ion thrusters, which are up to ten times more efficient than conventional rockets.

Dawn's mission is to visit two of the largest protoplanets in the Solar System: Vesta and Ceres. The massive tidal forces from Jupiter prevented them from becoming full planets billions of years ago and this gives scientists a way of studying the conditions of the early Solar System.

Dawn reached Vesta in 2011 and spent a year orbiting it. It's now on its way to Ceres and will arrive in February 2015. The craft uses visible light, infrared, gamma-ray and neutron spectrometers to map the surface of these bodies, as well as probe their interiors. It will be the first spacecraft to orbit two different bodies beyond Earth and will just beat New Horizons to be the first to orbit a dwarf planet.



The Dawn spacecraft bus pictured after the installation of its high-gain antenna

By the numbers

$446 MILLION

Final cost of the Dawn mission.

1,218kg

Dawn's weight at launch.

1,680 days

A year on Ceres is equal to 4.6 Earth years.

360,000

The number of names that are on Dawn's memory chip.

1807

The year Vesta was discovered

6kg

This much water evaporates from Ceres every second.

425 kilograms

Dawn began with this much Xenon propellant.

9.5×10^{20} kg

Ceres contains nearly a third of the mass of the Asteroid Belt.

1,300W

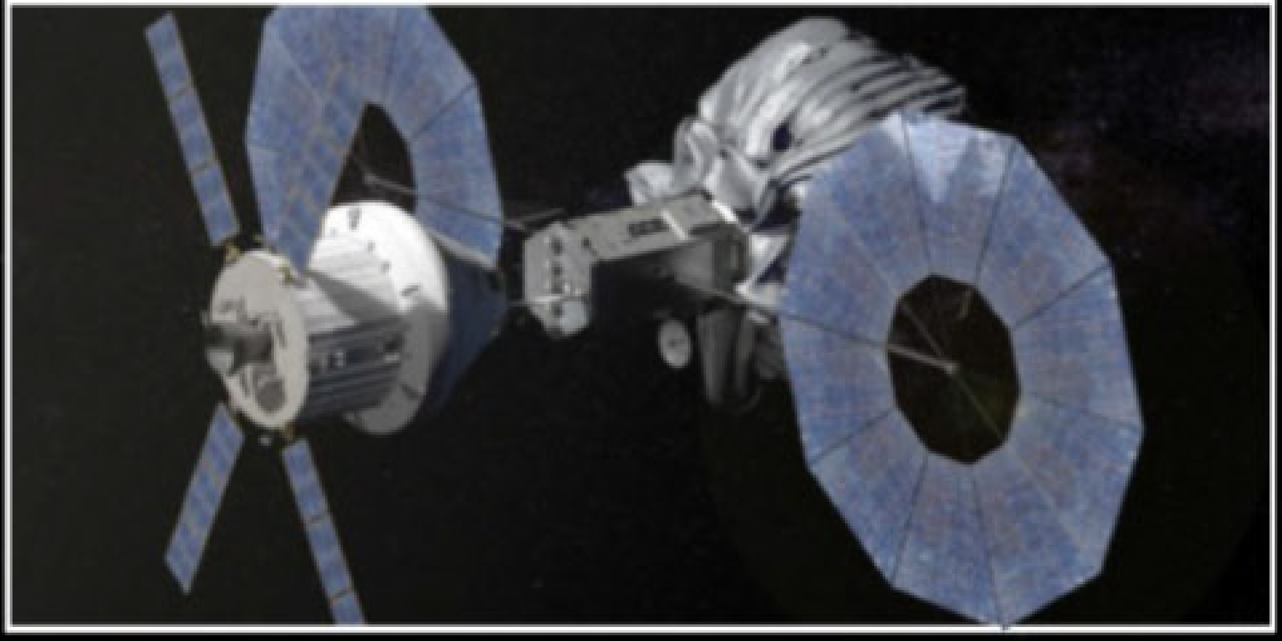
Dawn's solar panels generate enough electricity to power a travel kettle.

5 Asteroid retrieval

NASA's proposed Asteroid Retrieval & Utilisation (ARU) mission exists mostly to give astronauts something to do, which is a lot more important than it sounds. A manned landing on Mars is still a long way off, so NASA needs a challenge to test new technologies and inspire public interest for another generation. The goal is not just to visit an asteroid, but actually change its orbit. To do this the asteroid has to be large enough to be detected using Earth-based telescopes, but small enough that it can still be moved. This works out to be something like seven metres (23 feet) across and weighing around 500 tons. The first phase of the mission will send a robotic spacecraft powered by Solar Electric Propulsion. Aided by a gravitational boost from the Moon, this spacecraft will take about four years to reach and manoeuvre the asteroid. Using a huge expanding bag, the asteroid is snagged and its spin halted over a period of about 90 days. Then the spacecraft will use its thrusters to nudge the asteroid slowly out of its orbit. This could take as long as seven years, depending on the exact mass and orbit of the asteroid, but eventually it will be parked in a high retrograde orbit around the Moon.

At this point the second phase kicks in, with a Space Launch System heavy-lift rocket taking a manned Orion spacecraft on a nine-day journey to intercept the asteroid in its new orbit. This could happen in the 2020s. Astronauts could spend up to six days performing experiments and collecting samples from the asteroid. While this is undoubtedly much more expensive than unmanned asteroid sample-return missions, it's a key proving ground for the technology to take humans to Mars.

The Apollo missions returned 382kg (842lb) of Moon rocks. A captured asteroid could give astronauts 500 tons to work on



6 Land on a comet

Harpoon
As soon as it touches down, Philae will use a harpoon to anchor itself to the surface, to avoid bouncing back into space.

Soft landing
The comet is only about four kilometres (2.5 miles) in diameter and so has negligible gravity. Philae doesn't need thrusters to slow itself down.

Vent hazard
As well as a very uneven surface, there may be jets of carbon dioxide, methane and ammonia to contend with.

The Philae lander will be the first to attempt a soft landing on a comet. It's travelling aboard the European Space Agency's Rosetta spacecraft that was launched in 2004 and since May this year has been gradually slowing down to match velocity with comet 67P/Churyumov-Gerasimenko. Philae carries ten different instruments to sample the surface composition and remotely probe the core. Comets are blacker than tarmac and this is thought to be because they are essentially very dirty snowballs. The ice evaporates from the top few metres, leaving a tar-like crust. This is rich in organic compounds – possibly including amino acids and even the building blocks of DNA!

Fossil planets

Professor Christopher Russell, Dawn mission principal investigator, UCLA

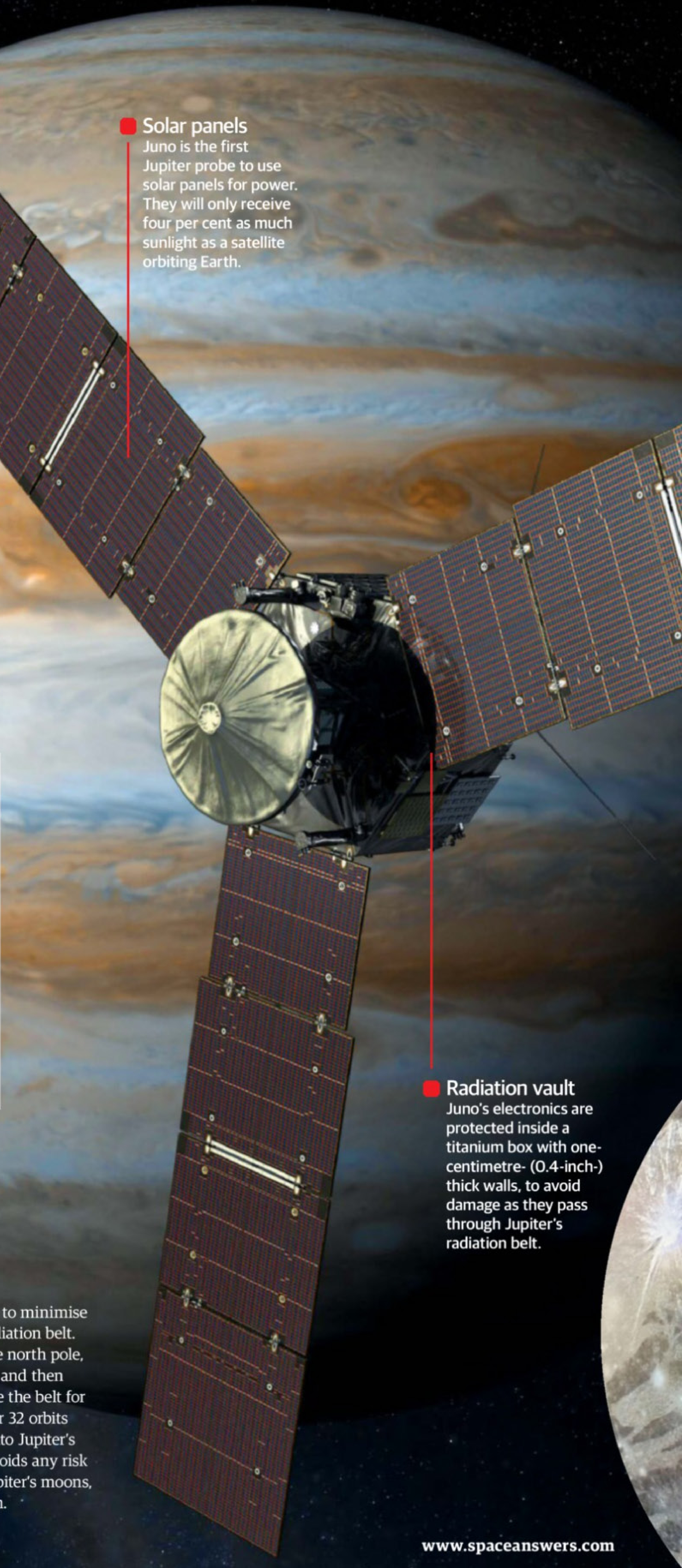
What can studying asteroids teach us about the rest of the Solar System?
The intact asteroids such as Vesta and Ceres are simpler bodies that have changed less than the larger planets since formation. So they tell us better what early conditions were like and how a planet forms.

Why are Vesta and Ceres so different in their physical makeup?
Vesta was formed first, when there was a lot of radioactive aluminium-26 around, so when it condensed it trapped the aluminium-26. The radioactive heating melted Vesta and it differentiated, formed a core and lost most of its water, leaving silicate rock on top of the iron core. Ceres formed without radioactive heating, stayed cool and kept its water.

How do dwarf planets like Ceres differ from the moons of Saturn and Jupiter?
[These moons managed to keep] even more water in general than Ceres retained (except Io, which lost most of its water).

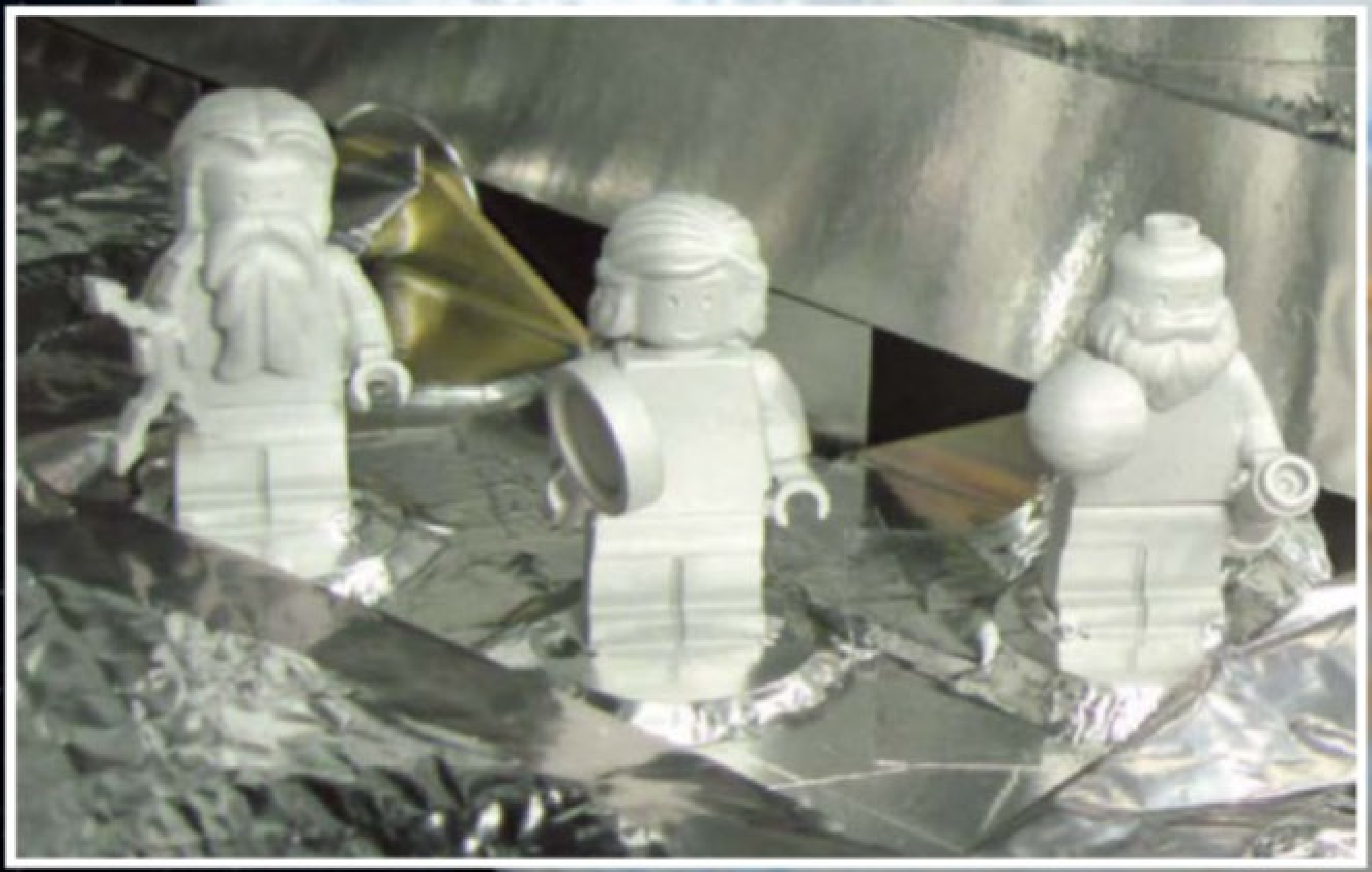
Reaching further

The further we travel from Earth, the bigger the challenge becomes. Jupiter has radiation belts much more powerful than Earth's, while Mercury is hot enough to de-solder electronic components and so on. These environments rule out manned missions, but even building unmanned probes that can survive these rigours is difficult. Until recently, most of the information we had on these distant planets was from brief glimpses, but a new generation of orbiter missions is en route. Soon we will have new views of the farthest corners of the Solar System.



Solar panels
Juno is the first Jupiter probe to use solar panels for power. They will only receive four per cent as much sunlight as a satellite orbiting Earth.

Radiation vault
Juno's electronics are protected inside a titanium box with one-centimetre- (0.4-inch-) thick walls, to avoid damage as they pass through Jupiter's radiation belt.

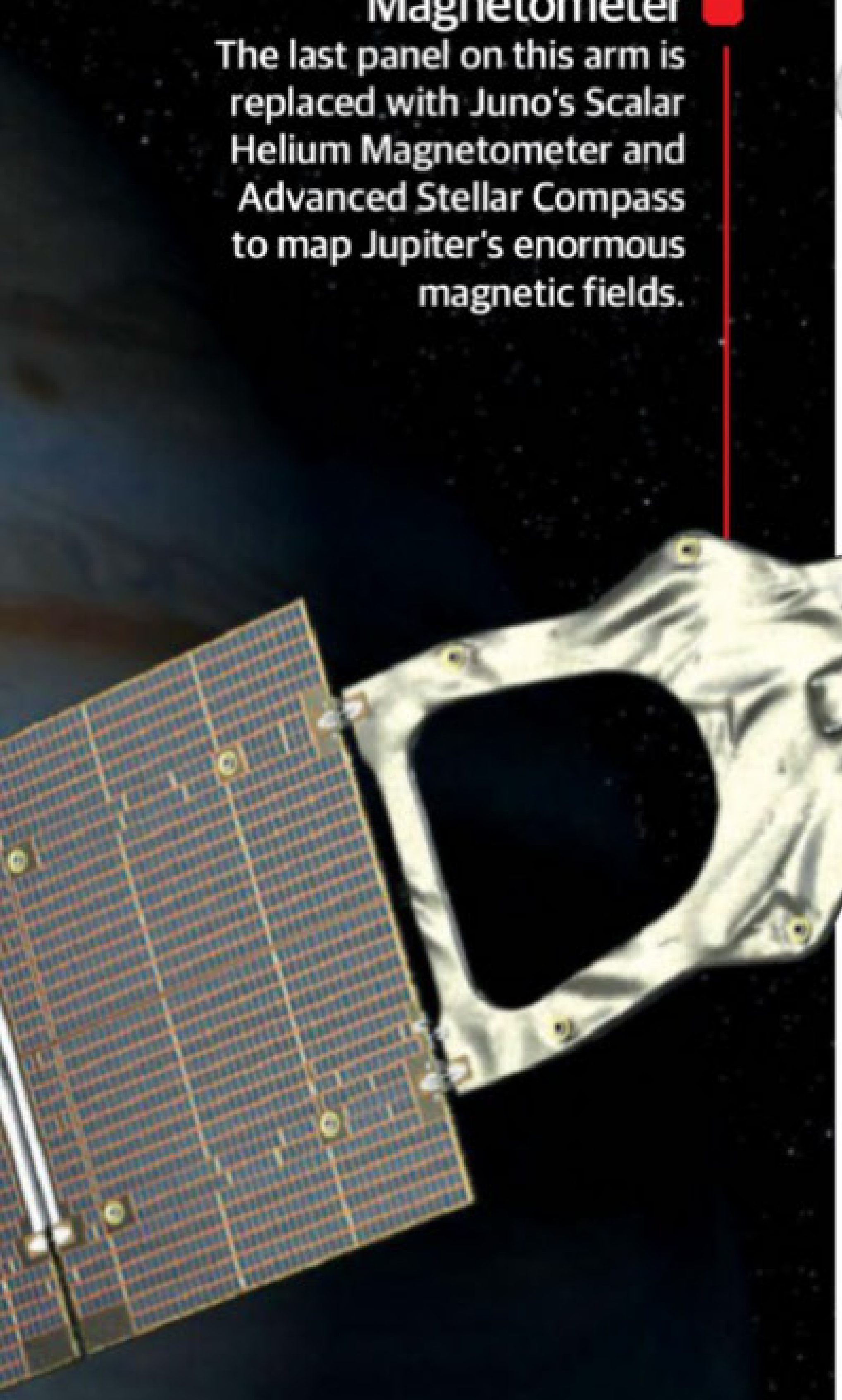


Juno carries three Lego minifigures: the Roman gods Jupiter and Juno and the astronomer Galileo. The aluminium minifigures cost £3,000 ($5,000) each

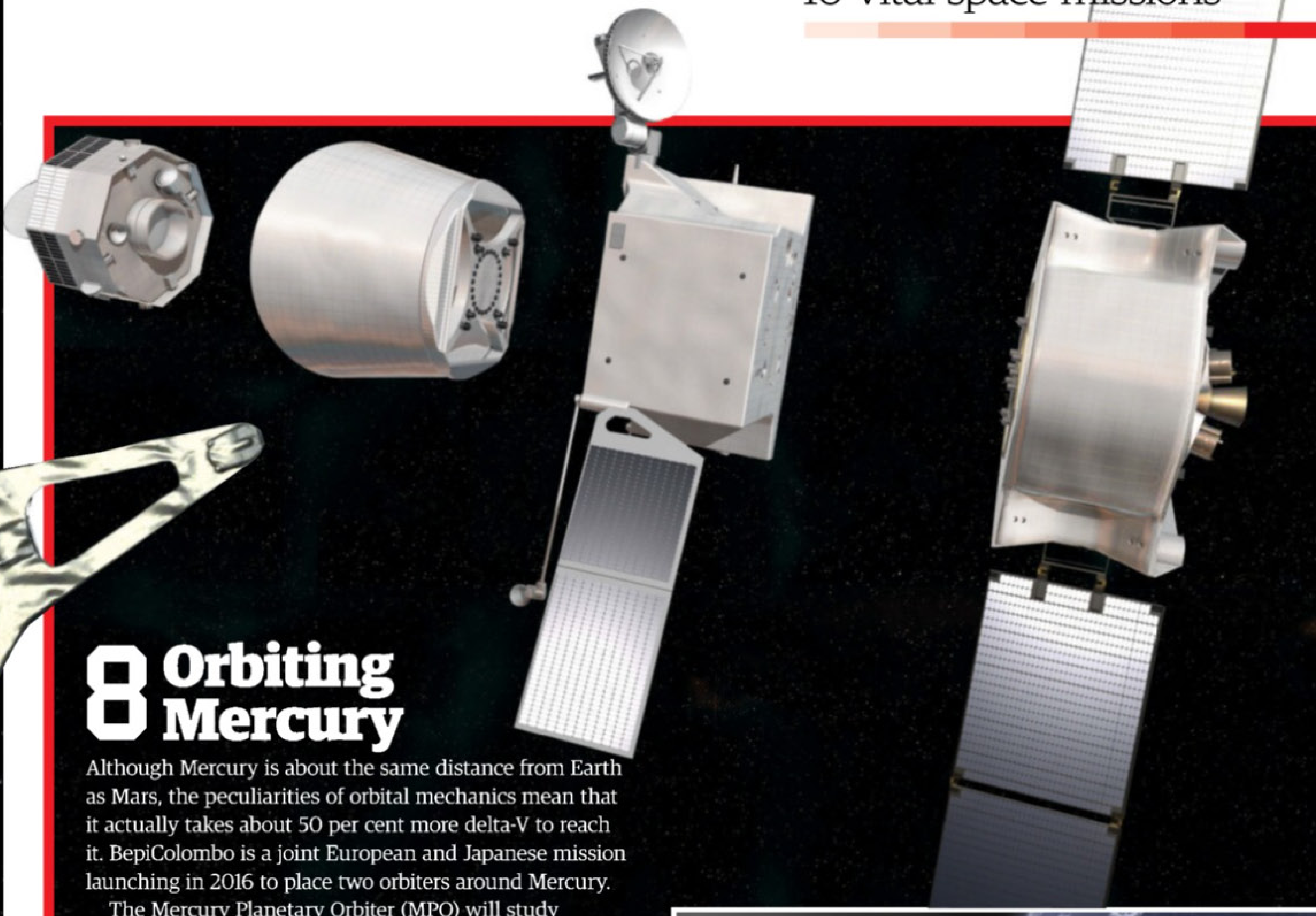
7 Studying Jupiter's atmosphere

NASA's Juno spacecraft is about halfway through its five-year journey to Jupiter. When it arrives it will enter a highly elliptical ten-day orbit that passes just 5,000 kilometres (3,107 miles) above Jupiter's cloud tops at its closest point. Juno will be able to accurately measure the amount of water in Jupiter and find out whether it has a rocky core. Both of these are important to improve our understanding of planet formation.

Juno's orbit has been chosen to minimise exposure to Jupiter's deadly radiation belt. It will dive under the belt at the north pole, where the radiation is weakest, and then exit at the south to fly far above the belt for the remainder of the orbit. After 32 orbits it will be deliberately steered into Jupiter's atmosphere to burn up. This avoids any risk of Juno crashing into one of Jupiter's moons, potentially contaminating them.



Magnetometer
The last panel on this arm is replaced with Juno's Scalar Helium Magnetometer and Advanced Stellar Compass to map Jupiter's enormous magnetic fields.

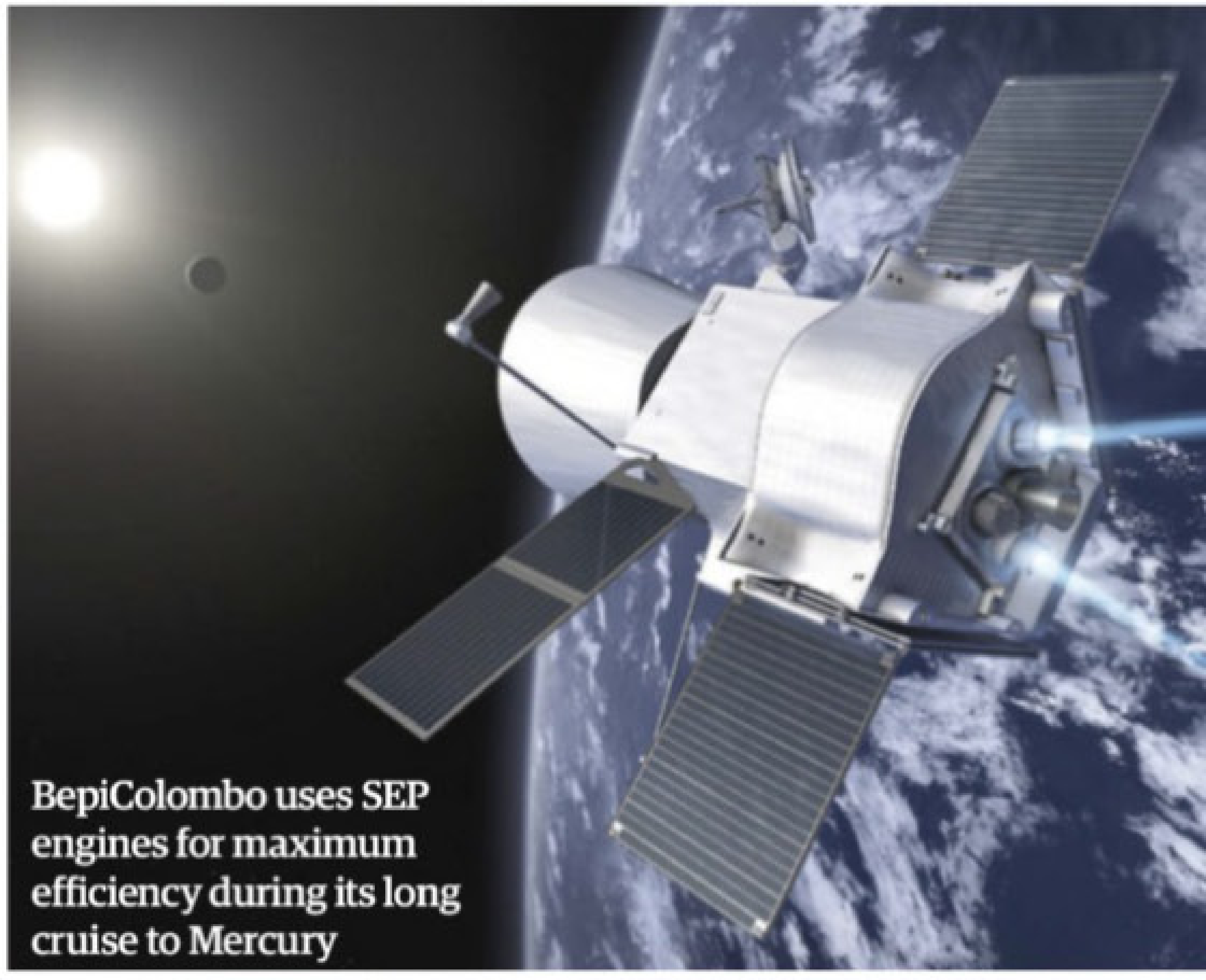


8 Orbiting Mercury

Although Mercury is about the same distance from Earth as Mars, the peculiarities of orbital mechanics mean that it actually takes about 50 per cent more delta-V to reach it. BepiColombo is a joint European and Japanese mission launching in 2016 to place two orbiters around Mercury.

The Mercury Planetary Orbiter (MPO) will study the planet's composition and its tenuous atmosphere. The smaller Mercury Magnetospheric Orbiter (MMO) will analyse its magnetic field. Because Mercury is so close to the Sun, these satellites will need to cope with temperatures of over 350 degrees Celsius (662 degrees Fahrenheit). In fact, the cruise stage that carries them to Mercury will actually need to rotate its solar panels partially away from the Sun as it draws closer, to avoid overloading the SEP system!

Astonishingly, considering the surface temperatures, it's thought that Mercury might have ice lurking in some craters near the poles that are in permanent shadow. The MPO carries an instrument to look for this, providing an essential resource if a manned landing mission is ever attempted in the future. BepiColombo will also provide one of the most rigorous tests of Einstein's theory of general relativity.



BepiColombo uses SEP engines for maximum efficiency during its long cruise to Mercury

9 Exploring Jupiter's moons

The icy moons of Jupiter – Ganymede, Callisto and Europa – offer the best chance of finding extraterrestrial life. This is because they all have a lot of water. Most of it is in the form of ice, but some is believed to exist as underground oceans, heated by tidal stretching and compression from Jupiter. The JUpiter ICy moons Explorer (JUICE) will be the first probe to actually orbit one of these moons – all previous missions have only been flybys. Its complex trajectory involves close encounters with the three moons, as it orbits Jupiter for two and a half years before settling into orbit around Ganymede for another eight months.

JUICE is due to launch in 2022, to arrive at Jupiter by 2030. It carries ten instruments to probe beneath the surface of each of the moons, looking for signs of biological activity. The Russian Space Research Institute is also considering a Ganymede lander craft that would ride along with JUICE.

Ganymede is Jupiter's largest moon. This photo mosaic from Voyager 1 shows evidence of earthquakes and surface erosion

10 Pluto and beyond

No spacecraft has ever visited Pluto. The best images we have, from the Faint Object Camera on the Hubble Space Telescope, show nothing more than a blurry, dappled blob. That's going to change in July next year, when NASA's New Horizons spacecraft will fly within 10,000 kilometres (6,214 miles) of Pluto. At the point of closest approach, it should be able to resolve features as small as two kilometres (1.24 miles) across, including any extra moons Pluto might have.

New Horizons is roughly the size and shape of a grand piano. It was launched in 2006 and has flown a relatively direct course to Pluto, making just one gravitational slingshot manoeuvre past Jupiter. That's still a journey of over ten years though and New Horizons has spent most of this time in a hibernation state to preserve its systems. After it passes Pluto, the mission will continue on into the Kuiper Belt. Pluto and its largest moon Charon are thought to be the largest of the Kuiper Belt Objects (KBOs) but there could be 100,000 bodies over 100 kilometres (62 miles) in diameter.

As well as its payload of seven instruments, New Horizons carries several mementos, including about 30 grams (one ounce) of the ashes of Clyde Tombaugh, who discovered Pluto in 1930.

New Horizons is one of very few spacecraft to be nuclear powered. The radioisotope thermoelectric generator (RTG) contains 11 kilograms (24 pounds) of plutonium-238 oxide pellets

Rarified atmosphere

Professor Fran Bagenal, New Horizons mission co-investigator, University of Colorado

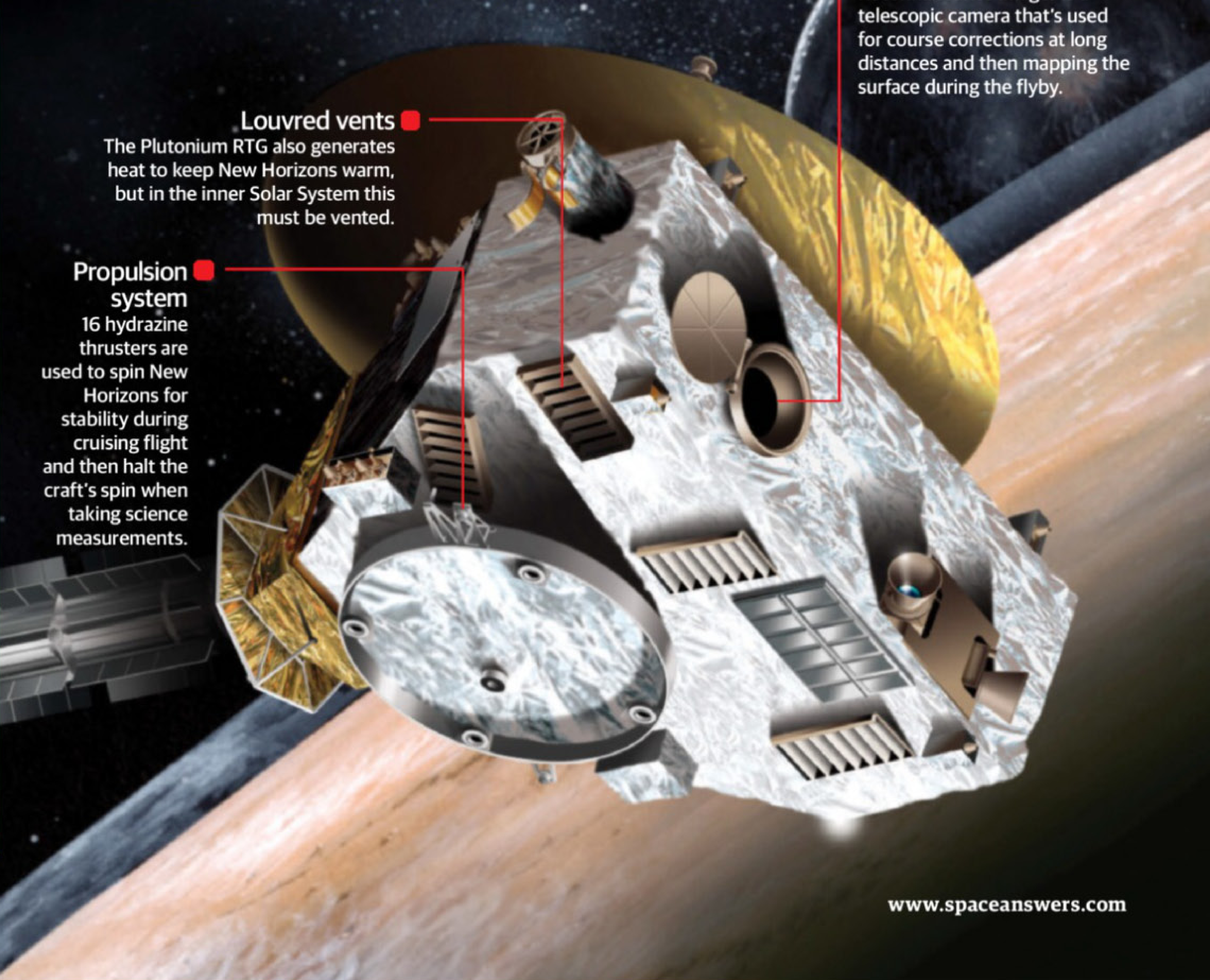
How much do we already know about Pluto and Charon?
We know their size, temperature, colour and surface composition, but we have no real idea of what they look like or the processes that are operating on them.

What do you hope to learn about their atmospheres?
We suspect that Pluto's atmosphere (mostly nitrogen, like Earth, with some methane and carbon monoxide) is escaping its weak gravity. We want to learn how much of the atmosphere is escaping and how. Charon probably does not have an atmosphere, but is embedded in the gases escaping Pluto.

How many other dwarf planets could there be in the Kuiper Belt?
We've looked pretty hard, so the answer is probably not very many. At most a handful, perhaps.

What's special about Pluto?
It was discovered in 1930 – 62 years before the next Kuiper Belt Object. We now know it has five moons! Several other objects also have moons, but probably not as many.

New Horizons at the Kennedy Space Center's Payload Hazardous Servicing Facility



LORRI
The Long Range Reconnaissance Imager is a telescopic camera that's used for course corrections at long distances and then mapping the surface during the flyby.

Louvred vents
The Plutonium RTG also generates heat to keep New Horizons warm, but in the inner Solar System this must be vented.

Propulsion system
16 hydrazine thrusters are used to spin New Horizons for stability during cruising flight and then halt the craft's spin when taking science measurements.

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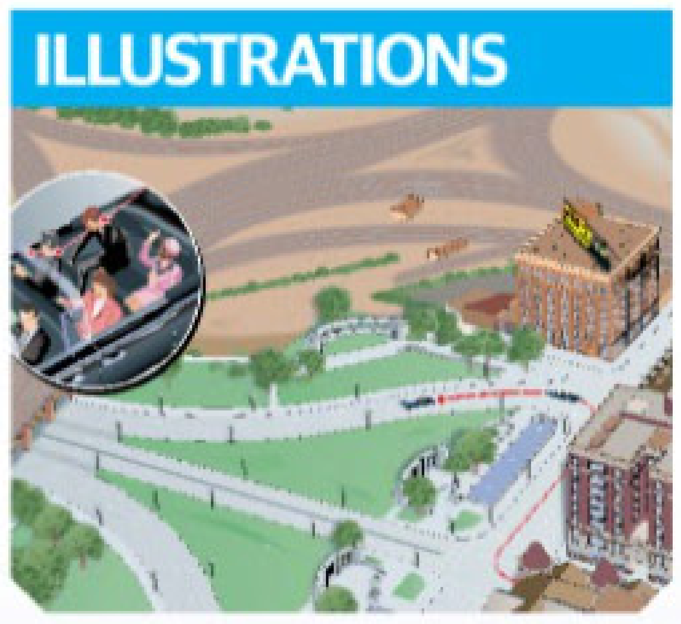

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10 Amazing facts

Andromeda

It was once classed as a nebula

Before the true scale of the universe was realised, what is now known to be the rim of our own Milky Way was thought to be the edge of space. Within that the Andromeda galaxy (M31), little more than a fuzzy blur in the sky to all but the most powerful telescopes of the earliest 20th century, was considered to be a mere collection of forming stars and cosmic dust clouds. This meant it was originally called the Great Andromeda nebula.

A trillion stars can be found here

Although the Milky Way is probably the most massive in the galactic Local Group, Andromeda is the biggest by volume. Our neighbouring galaxy also contains around twice the number of stars as our own galaxy, according to observations made by the Spitzer Space Telescope.

It's huge!

With an enormous diameter of around 220,000 light years across, Andromeda is over 2.5 times longer than the entire Milky Way and appears longer than the full Moon in the night sky. Despite it being further away than any visible star, you can see it with the naked eye and it's still the closest known galaxy to our own.

You can see it with the naked eye

Andromeda has been known since ancient times because, at just 2.5 million light years away, this large, bright galaxy is visible with the naked eye. On a clear night with little light pollution, it can be seen as a diffuse blur, with the central region clearly visible through a good pair of binoculars. Larger telescopes provide even more-spectacular views of this impressive galaxy.

We know its entire life history

The major benefit of Andromeda being such a conspicuous night-sky object is that it's been studied and scrutinised by astronomers for decades. It was born 10 billion years ago out of the merger of many smaller protogalaxies and then, around 8 billion years ago, it ran head-on into another galaxy to form a giant that became the M31 galaxy we see today.

Andromeda holds a grave secret

To most telescopes, Andromeda's giant stellar stream will look like a wispy cloud that orbits the galaxy like a huge celestial ring. In fact, this is the remains of an ancient companion that was ripped up and consumed by M31 billions of years ago. The clouds are actually the remains of the stars that once formed this galaxy and are easily resolved by space telescopes such as Hubble.

Dozens of black holes lie here

The centre of M31 is home to 26 known black hole candidates and many more have been picked out by the Chandra X-ray Observatory. Like our own galaxy, there's also a supermassive black hole at the centre, with two others possibly orbiting as a binary, with a mass around 140 million times that of the Sun.

Andromeda is a galactic bully

Andromeda has numerous satellite galaxies, including 14 dwarf galaxies that it regularly bullies. Both M32 and M110 have had encounters with M31 that they've come off worse from: a stream of stars was ripped away from M110 while Andromeda robbed M32 of a large part of its stellar disk at some point in the distant past.

It's on a collision course

Whereas most of the rest of the universe is accelerating away from our galaxy, Andromeda is blue-shifted, meaning it's moving towards us. Both the Milky Way and Andromeda are moving towards each other at a rate of 120 kilometres (75 miles) a second, putting them on course for a galactic smash-up in around 4 billion years.

It prompted the Great Debate

In 1920, the Andromeda galaxy prompted a fierce debate between two prominent astronomers, Harlow Shapley and Heber Curtis. Shapley believed that Andromeda and the Pinwheel galaxy were nebulas found within the Milky Way, based on the fact that if they weren't, it would put Andromeda an 'impossible' multi-million-light-year distance from us. Curtis argued that this was in fact, the case. Work by Edwin Hubble, Henrietta Leavitt et al eventually proved Curtis right.

The Andromeda galaxy, also known as Messier 31 or NGC 224, in the constellation Andromeda

© Alamy

Fishing on other worlds

Could space fishing be the answer to a low-cost sample-and-return mission?

Despite a raft of probes and landers reaching the surface of far-off planets, moons and eventually comets, nothing quite beats having extraterrestrial samples in your hands to analyse. However, the high cost this entails has been extremely prohibitive up until now. Scientists have had to be able to find a spot to land, touch down gently on the surface, collect samples and finally have enough fuel left to escape the gravity of their landing site. This takes time, precision and money, so the quest to find a practical way to collect samples cheaply has been a high priority for a long time. Enter professor Robert Winglee and his team from the University of Washington, who have come up with the concept of fishing for samples in space.

The idea is beautiful in its simplicity – a probe would near an object of interest, open up a tube and fire a tethered rocket to the surface of the planet or moon. This would smash into the ground and, hopefully, a few feet into it. The impact would force material through an opening in the top of the harpoon, where it would be stored. The device would then be reeled back into the probe, much like a fisherman would reel in a fish. This would then be safely stored until the spacecraft's return to Earth, where researchers could analyse data with their own eyes, hands and instruments, rather than relying on machinery millions of miles away.

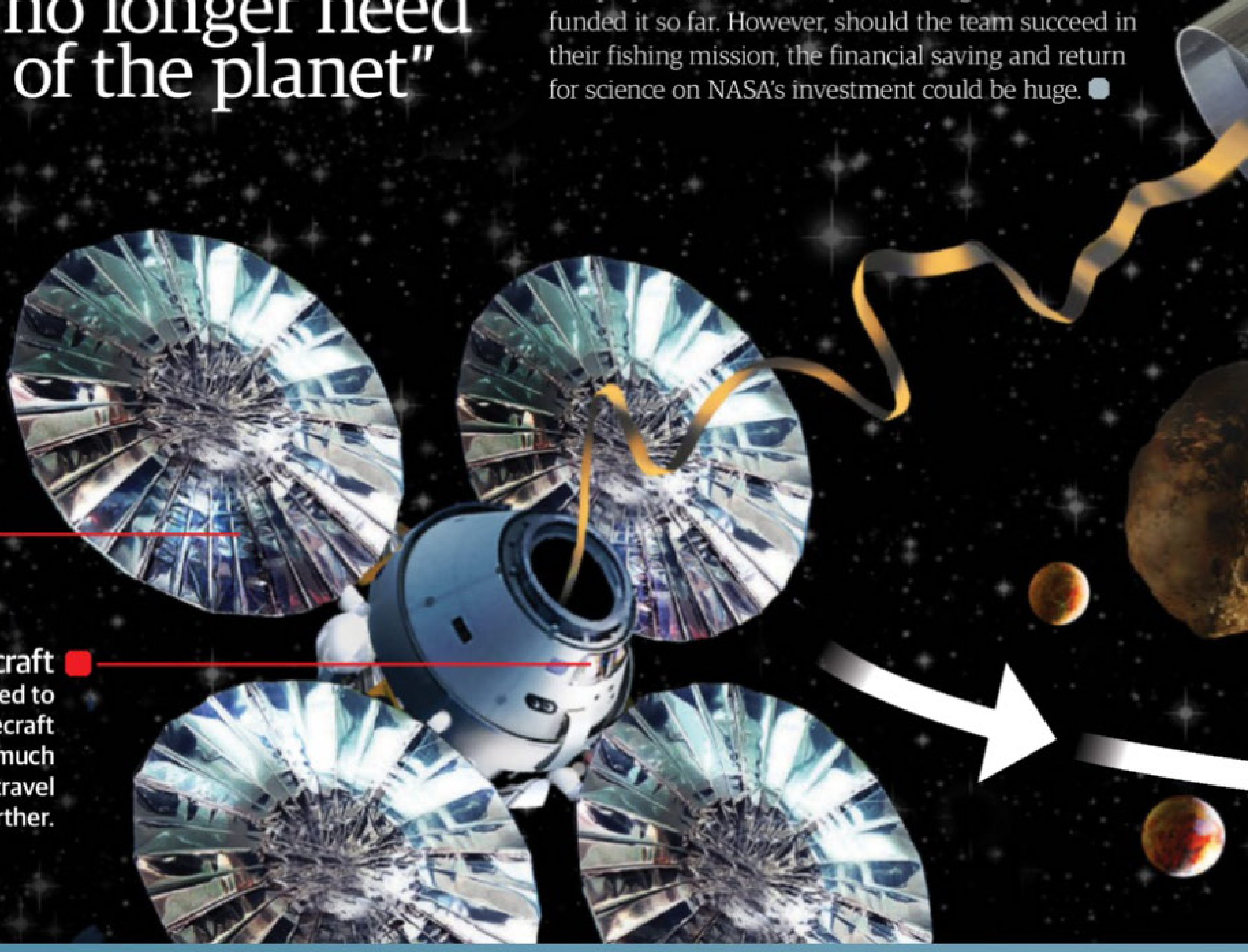
Apart from the advantage of returning data to scientists, there are a number of pluses to space fishing – mainly that the spacecraft would no longer need to land on the surface of the planet and get trapped in its gravitational field. This would mean an awful lot less fuel used, so that missions could be completed on a far smaller budget, or the spacecraft could travel much further before returning home.

The time taken to prepare for the mission would be reduced, as a safe landing spot would not need to be found. The mission itself would be much quicker too, as the spacecraft would only be passing by a place of interest, rather than landing, stopping, collecting and launching again.

The main challenge to Winglee and his team so far has been the construction of the rocket that gets fired into the surface of the planet or moon. It has to be phenomenally strong to withstand the force that will accompany the firing as well as the impact as it attempts to burrow into its target. Currently it's made of steel and is able to power through 1.8 metres (6 feet) of concrete, but it will have much tougher material to get through than that in outer space. The inner casing of the craft also has to withstand a huge shock and stay intact, as it will be carrying valuable samples back to Earth.

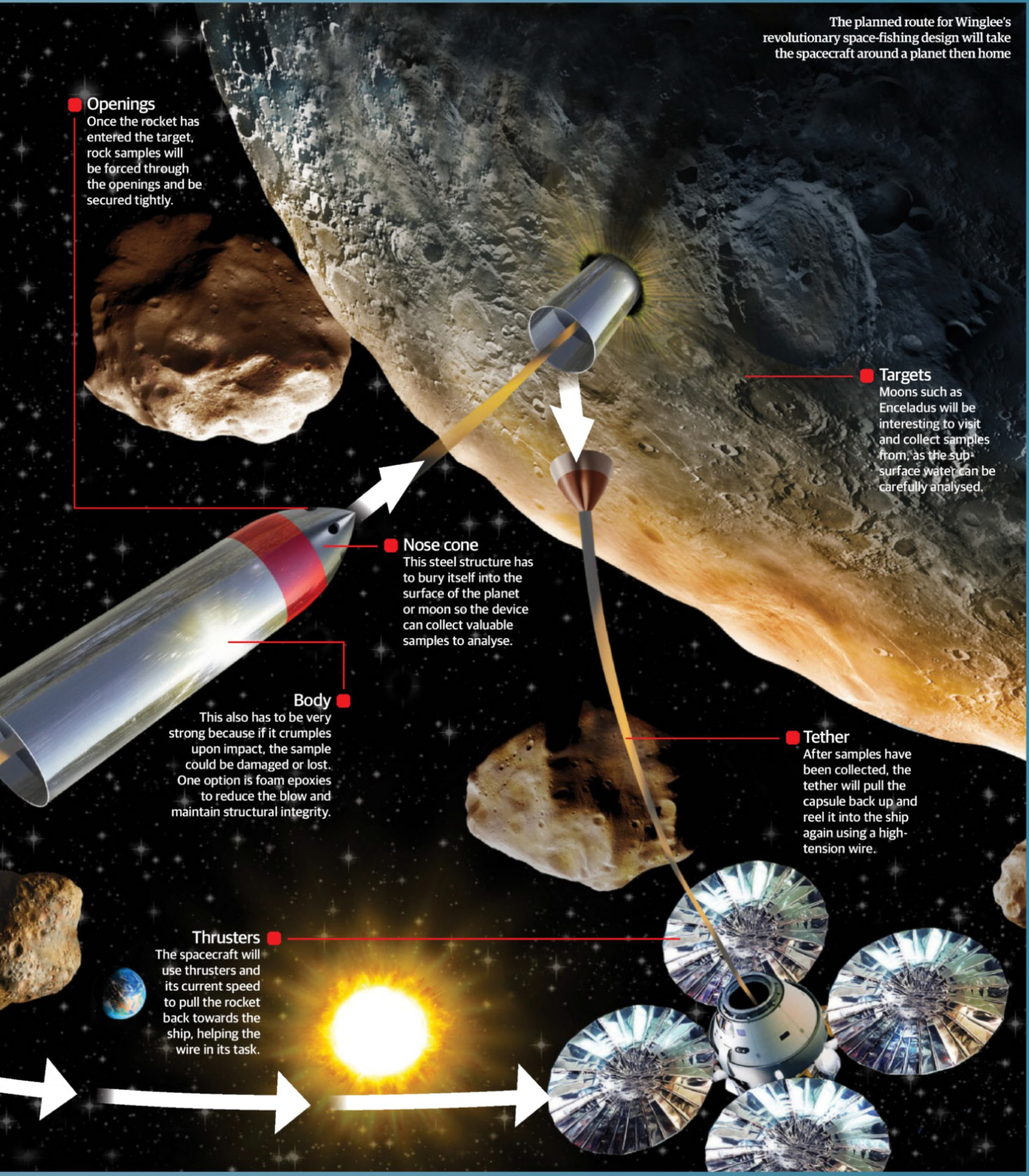
The project is currently at the Phase II stage, meaning that NASA's Innovative Advanced Concepts (NIAC) is providing Winglee with a further £300,000 ($500,000) to enable him and his team to research this project for two more years, having already funded it so far. However, should the team succeed in their fishing mission, the financial saving and return for science on NASA's investment could be huge. ■

> "The spacecraft would no longer need to land on the surface of the planet"



Analysis
One plan is for the spacecraft to be filled with instruments, which will enable analysis of the samples to occur while the spacecraft is travelling.

Spacecraft
Without the need to land, the spacecraft can run with much less fuel or travel much further.



The planned route for Winglee's revolutionary space-fishing design will take the spacecraft around a planet then home

Openings
Once the rocket has entered the target, rock samples will be forced through the openings and be secured tightly.

Targets
Moons such as Enceladus will be interesting to visit and collect samples from, as the sub-surface water can be carefully analysed.

Nose cone
This steel structure has to bury itself into the surface of the planet or moon so the device can collect valuable samples to analyse.

Body
This also has to be very strong because if it crumples upon impact, the sample could be damaged or lost. One option is foam epoxies to reduce the blow and maintain structural integrity.

Tether
After samples have been collected, the tether will pull the capsule back up and reel it into the ship again using a high-tension wire.

Thrusters
The spacecraft will use thrusters and its current speed to pull the rocket back towards the ship, helping the wire in its task.

© Adrian Chesterman

ANCIENT WHITE DWARF STARS

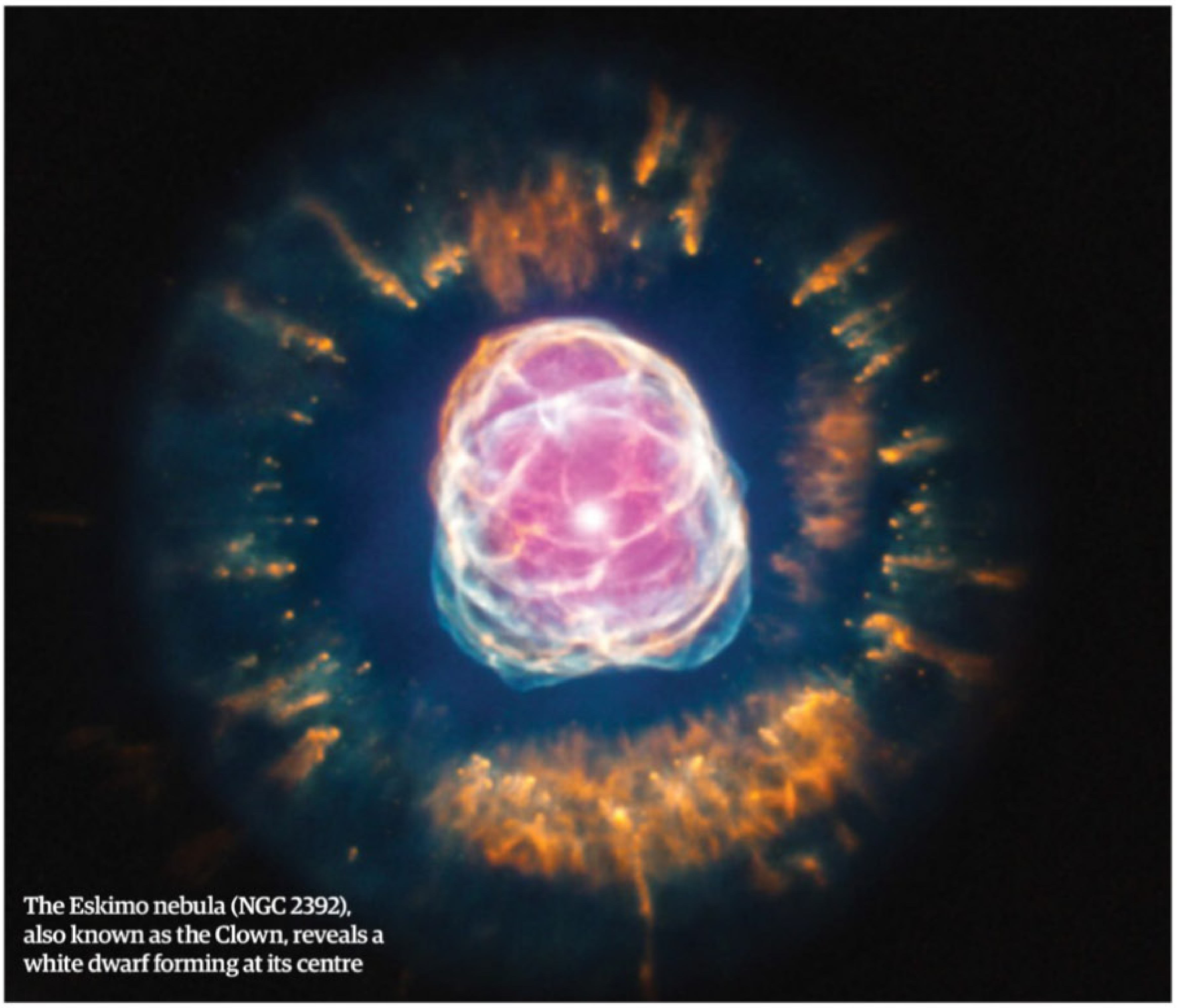
They're hot, they're small and technically they're dead. Meet the old-age stellar remnants that have a multi-million-year-long tale to tell

Written by Gemma Lavender

Welcome to the stellar afterlife, when the stars like our Sun have burnt themselves out, shedding their skins to leave behind a dead core. These stellar remnants are the white dwarfs, pint-sized objects that are quite unlike any other. No bigger than Earth in diameter, they're white-hot and slowly cooling as they fade away over billions and trillions of years. Eventually they become stellar ghosts – mere shadows of their former selves.

97 per cent of stars in the universe will one day turn into these white dwarfs. In the cosmos' far future you would be hard-pressed to find a star that's burning with the aid of fusion, as it becomes littered with stellar corpses.

White dwarfs are made inside stars that are less massive than eight times the Sun. Stars that are any larger explode as supernovas, instead leaving behind a dark neutron star or an even darker, ravenous black hole. In contrast, white dwarfs are fiery members of the stellar underworld, with temperatures over 200,000 degrees Celsius (360,000 degrees Fahrenheit) when they're born. But if they are dead, how can they be so hot? Astronomers believe they get their incandescent heat because they used to be the cores of stars – the industrious powerhouse where lighter elements are burned and transformed into something heavier.



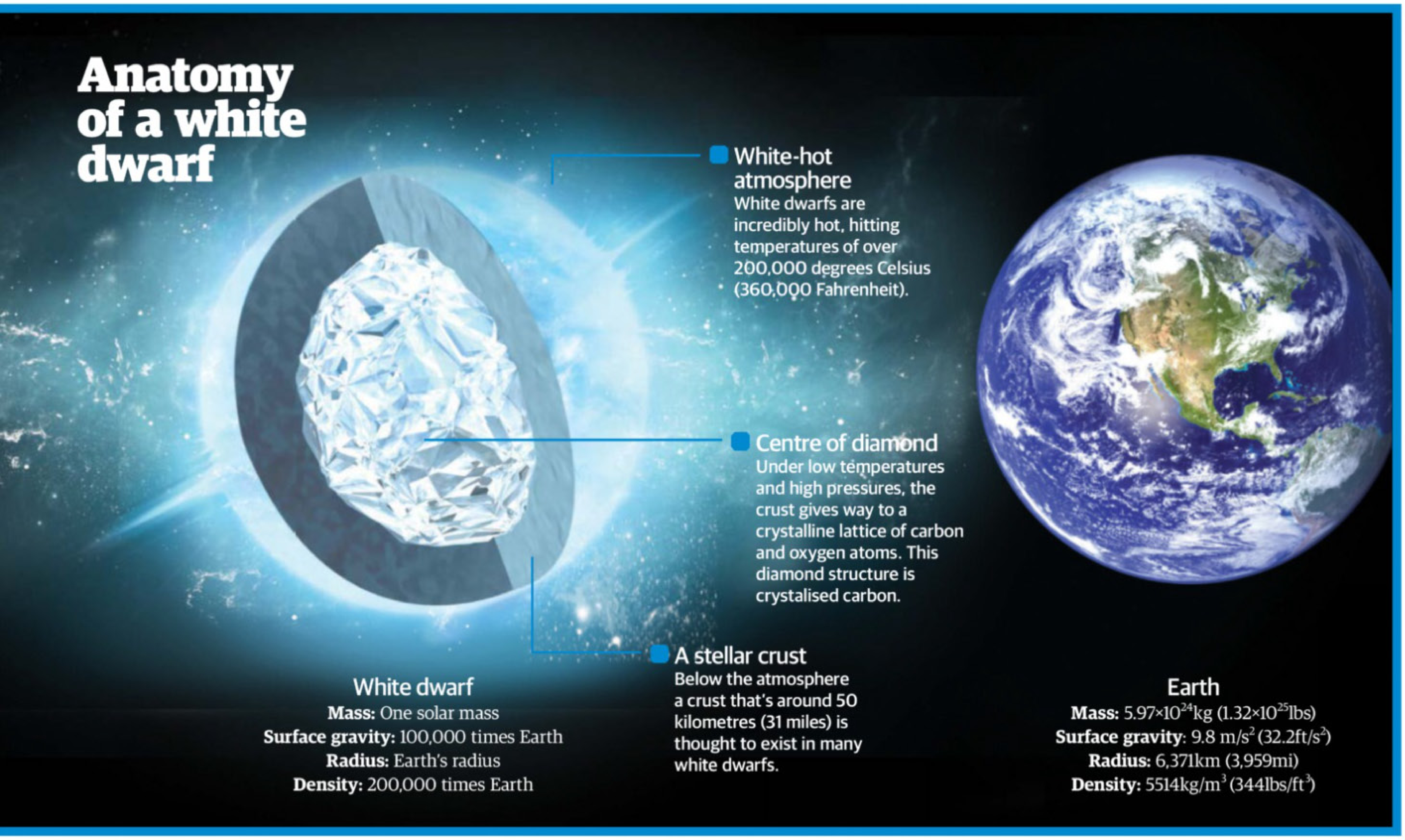
The Eskimo nebula (NGC 2392), also known as the Clown, reveals a white dwarf forming at its centre

When a star is created in a nebula, it collects hydrogen gas with its gravity from the nebula until the gaseous ball of the star is both hot and dense enough to erupt into life. Intense heat and light bursts from its centre, driven by nuclear fusion reactions that turn hydrogen gas into helium. A star like the Sun has enough hydrogen to fuse into helium for about 10 billion years and it's already nearly halfway through that lifespan. If we travel through time to see the final phase of our Sun's life, we'll see it start to run out of hydrogen. As a result, the centrepiece of our Solar System will begin to change. The nuclear fusions that breathed it into existence will no longer be able to continue as strongly at its heart, causing the Sun's insides to shrink.

It's not completely over for our Sun though, as its outer layers will still have the will to fight and they'll become hotter, taking over from the core to start nuclear reactions. A huge amount of energy will pour out from the Sun's outer envelope, causing it to expand into a monstrous red giant star whose swollen limbs will push further and further out into space. Here the two parts of the Sun will go in opposite directions. In a final push, the red giant puffs off its ruddy outer layers into a beautiful planetary nebula, which under the scrutiny of different wavebands glow in a myriad of colours.

Meanwhile the core continues to contract as its fusion grinds to a halt, getting smaller and smaller until it reaches a limit called an electron degeneracy pressure. Matter is so dense here that the subatomic

Anatomy of a white dwarf



White-hot atmosphere
White dwarfs are incredibly hot, hitting temperatures of over 200,000 degrees Celsius (360,000 Fahrenheit).

Centre of diamond
Under low temperatures and high pressures, the crust gives way to a crystalline lattice of carbon and oxygen atoms. This diamond structure is crystalised carbon.

A stellar crust
Below the atmosphere a crust that's around 50 kilometres (31 miles) is thought to exist in many white dwarfs.

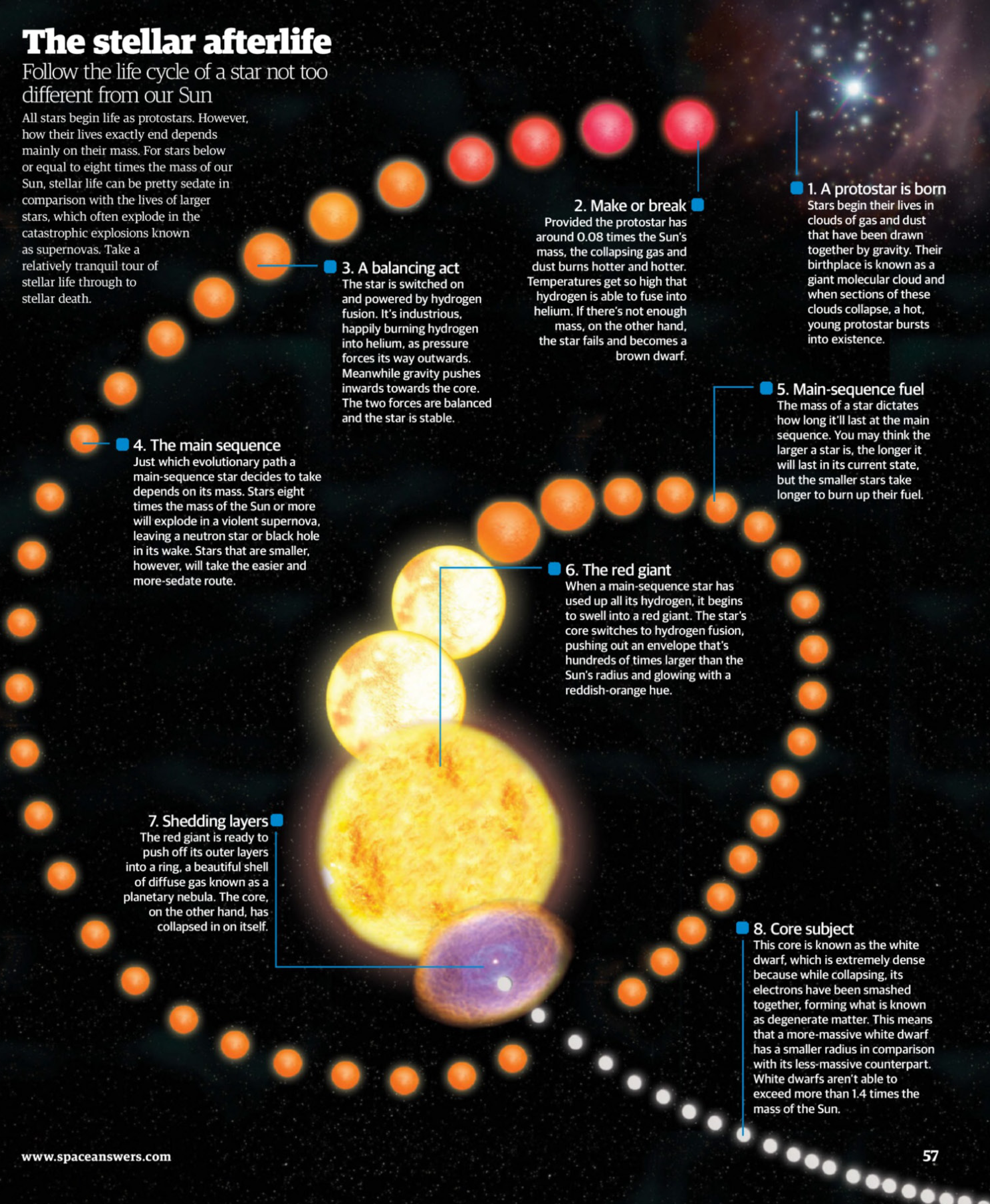
White dwarf
Mass: One solar mass
Surface gravity: 100,000 times Earth
Radius: Earth's radius
Density: 200,000 times Earth

Earth
Mass: 5.97×10^{24}kg (1.32×10^{25}lbs)
Surface gravity: 9.8 m/s^2 ($32.2 ft/s^2$)
Radius: 6,371km (3,959mi)
Density: 5514kg/m^3 (344lbs/ft^3)

The stellar afterlife

Follow the life cycle of a star not too different from our Sun

All stars begin life as protostars. However, how their lives exactly end depends mainly on their mass. For stars below or equal to eight times the mass of our Sun, stellar life can be pretty sedate in comparison with the lives of larger stars, which often explode in the catastrophic explosions known as supernovas. Take a relatively tranquil tour of stellar life through to stellar death.



1. A protostar is born

Stars begin their lives in clouds of gas and dust that have been drawn together by gravity. Their birthplace is known as a giant molecular cloud and when sections of these clouds collapse, a hot, young protostar bursts into existence.

2. Make or break

Provided the protostar has around 0.08 times the Sun's mass, the collapsing gas and dust burns hotter and hotter. Temperatures get so high that hydrogen is able to fuse into helium. If there's not enough mass, on the other hand, the star fails and becomes a brown dwarf.

3. A balancing act

The star is switched on and powered by hydrogen fusion. It's industrious, happily burning hydrogen into helium, as pressure forces its way outwards. Meanwhile gravity pushes inwards towards the core. The two forces are balanced and the star is stable.

4. The main sequence

Just which evolutionary path a main-sequence star decides to take depends on its mass. Stars eight times the mass of the Sun or more will explode in a violent supernova, leaving a neutron star or black hole in its wake. Stars that are smaller, however, will take the easier and more-sedate route.

5. Main-sequence fuel

The mass of a star dictates how long it'll last at the main sequence. You may think the larger a star is, the longer it will last in its current state, but the smaller stars take longer to burn up their fuel.

6. The red giant

When a main-sequence star has used up all its hydrogen, it begins to swell into a red giant. The star's core switches to hydrogen fusion, pushing out an envelope that's hundreds of times larger than the Sun's radius and glowing with a reddish-orange hue.

7. Shedding layers

The red giant is ready to push off its outer layers into a ring, a beautiful shell of diffuse gas known as a planetary nebula. The core, on the other hand, has collapsed in on itself.

8. Core subject

This core is known as the white dwarf, which is extremely dense because while collapsing, its electrons have been smashed together, forming what is known as degenerate matter. This means that a more-massive white dwarf has a smaller radius in comparison with its less-massive counterpart. White dwarfs aren't able to exceed more than 1.4 times the mass of the Sun.

particles known as electrons cannot pack together any further. The size white dwarfs reach before electron degeneracy pressure kicks in is about the size of a rocky planet like Earth. Neutron stars, created in supernovas, are even smaller and are about the size of a city.

Turn a telescope to a planetary nebula and the white dwarf can often be seen at its heart. However, over the course of a few tens of thousands of years, this star is left alone as what remains of the red giant's bulk dissipates into nothingness. Not all white dwarfs are completely alone, however, and some cluster together while others are not too far from us, astronomically speaking at least.

Sirius B, which rests 8.6 light years away and orbits Sirius, the brightest star in the sky, is our closest example of one of these ancient stars. While you can see Sirius blazing away in the constellation Canis Major with the naked eye, you won't be able to see Sirius B without the aid of a telescope and even then it's still a challenge to spot. Being in a constellation that resembles a great dog, we know Sirius as the Dog star, which means little Sirius B is affectionately known as its Pup. Free of Earth's atmosphere and the interference it can cause, the Hubble Space Telescope has snapped the best image of this binary.

Although Sirius and its Pup look like they are within touching distance of each other when we gaze at them, in reality their elliptical orbit takes them from 8 to 32 times the distance between Earth and the Sun. Because there are more double stars in the Milky Way galaxy than single ones, more often than not white dwarfs find themselves in binary systems like Sirius. These are much closer to their companion stars – having not yet reached the white dwarf stage – and are still creating energy by fusing hydrogen in their cores. Interestingly, sometimes they get so close that they begin to spiral into each other and this is when the cosmic fireworks really start.

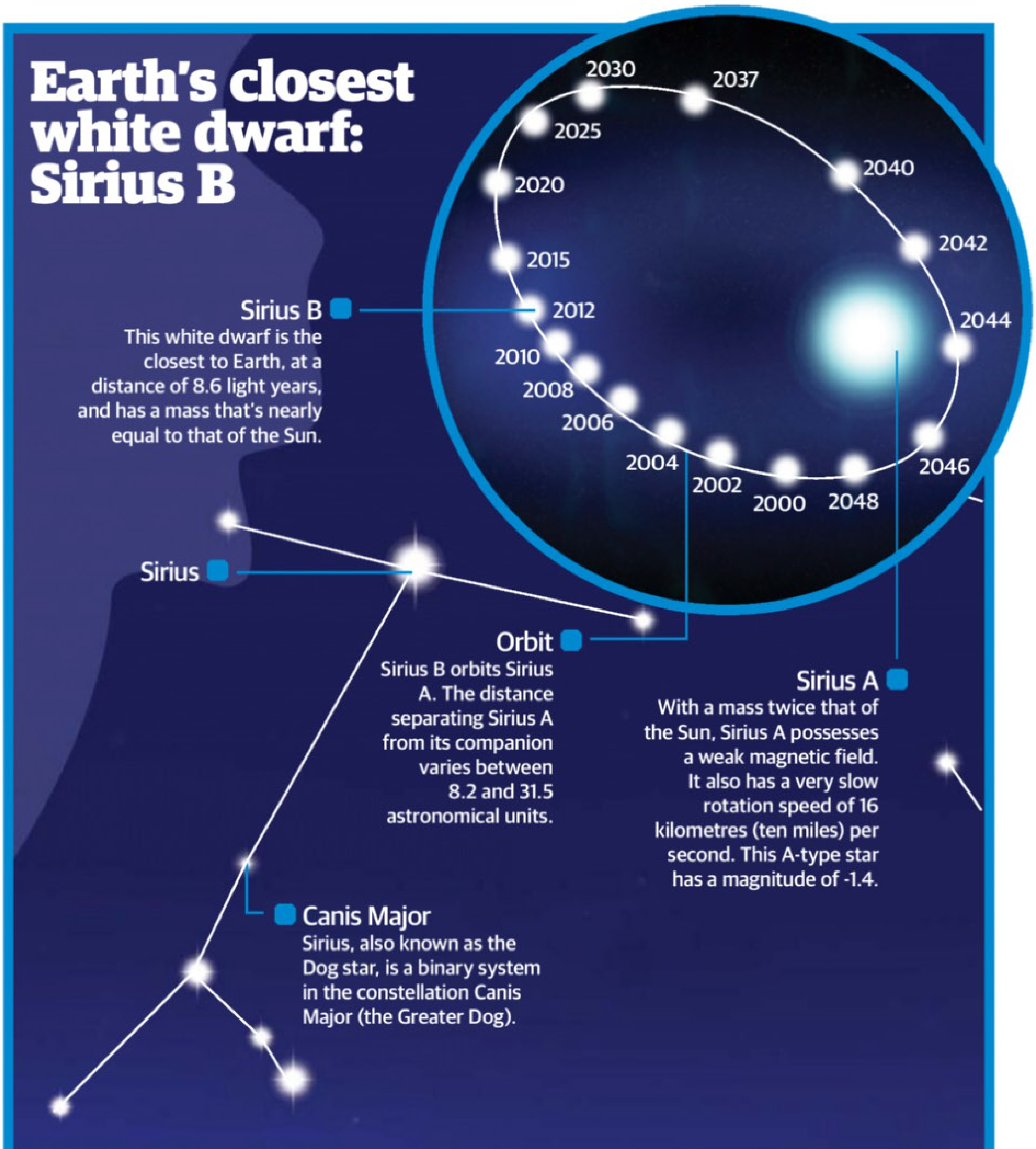
Imagine two stars, a happy stellar couple, with one a little more massive than the other. The rules of stellar evolution say that more-massive stars use up their hydrogen faster than smaller stars, so one will age faster than the other. The larger star goes through the motions of its evolution, leaving a white dwarf behind. Its companion star gets a front-row seat through the entire transition, yet happily continues as a normal star. Astronomers believe that they've seen the evidence of such an event – where two stars can be seen inside a planetary nebula. Having a companion star makes these beautiful objects all the more extravagant since it interacts with the gas shed by the red giant, creating a double-lobed shape.

However, the companion star isn't immune to feeling the effects of time. Eventually it too will get old, run out of hydrogen in its core, and evolve into a red giant and a white dwarf too. White dwarfs are small but aren't lightweights – Sirius B packs in almost as much mass as the Sun has into an object the size of a planet. White dwarf stars are more than half a million times denser than the Sun and their gravity is very strong. A matchbox filled with material scooped off the surface of a white dwarf would have a mass of over 20 tons.

When the white dwarf and its companion red giant are close, the white dwarf can sometimes find itself within the outer atmosphere of its monstrous

The Cat's Eye nebula has a very complex structure

> "A matchbox filled with material scooped off the surface of a white dwarf would have a mass of over 20 tons"



Earth's closest white dwarf: Sirius B

Sirius B
This white dwarf is the closest to Earth, at a distance of 8.6 light years, and has a mass that's nearly equal to that of the Sun.

Sirius

Orbit
Sirius B orbits Sirius A. The distance separating Sirius A from its companion varies between 8.2 and 31.5 astronomical units.

Sirius A
With a mass twice that of the Sun, Sirius A possesses a weak magnetic field. It also has a very slow rotation speed of 16 kilometres (ten miles) per second. This A-type star has a magnitude of -1.4.

Canis Major
Sirius, also known as the Dog star, is a binary system in the constellation Canis Major (the Greater Dog).

neighbour. It then starts to accumulate matter from it, pulling extra material onto its surface. This matter gathers in very dense pools that become so compact and get so hot that they actually ignite in a thermonuclear explosion on the dead star's surface. Such eruptions are so bright that we can see them from Earth. Yet, despite such a catastrophic force, the white dwarf survives. It isn't put off and proceeds to gather more mass to do it all over again, with explosions happening on a regular basis. This ancient star will eventually pay a price because of its continual need to steal from its companion.

Astronomers call this type of white dwarf a cataclysmic variable. One of the most famous of this kind is the star system RS Ophiuchi, which is 5,000 light years away and has experienced explosions in 1898, 1933, 1958, 1967, 1985 and 2006. The eventual fate of the white dwarf member of RS Ophiuchi is a doomed one: it will continue to strip so much mass from its companion that it will get increasingly massive and dense. This will result in an explosion of epic proportions - a type-Ia supernova that completely obliterates the star.

This form of stellar death is different to the supernovas that happen when massive stars collapse and explode. For a start, a type-Ia supernova is extremely reliable - they're always the same luminosity, which makes them easy to compare and astronomers can accurately judge how far away they are based on how bright they appear to us. Scientists call them standard candles, which are used to study how dark energy is causing the expansion of the universe to speed up, carrying galaxies and the supernovas in them further away from us.

The reason type-Ia supernovas appear with the same brightness is because they always explode at the same mass, which is 1.44 times that of our Sun. This is called the Chandrasekhar limit, after the genius Indian astrophysicist of the 20th century.

Not all white dwarfs are thieves, however. Some ancient stars aren't interested in stealing all the material they can from their companion, at least not great amounts. Some prefer the quieter and simplistic route, seeing out their years by steadily and slowly cooling down. These old stars will get to see their companions evolve as they gradually morph into more white dwarfs. We're now seeing double: two white dwarfs are circling each other in a stellar tango.

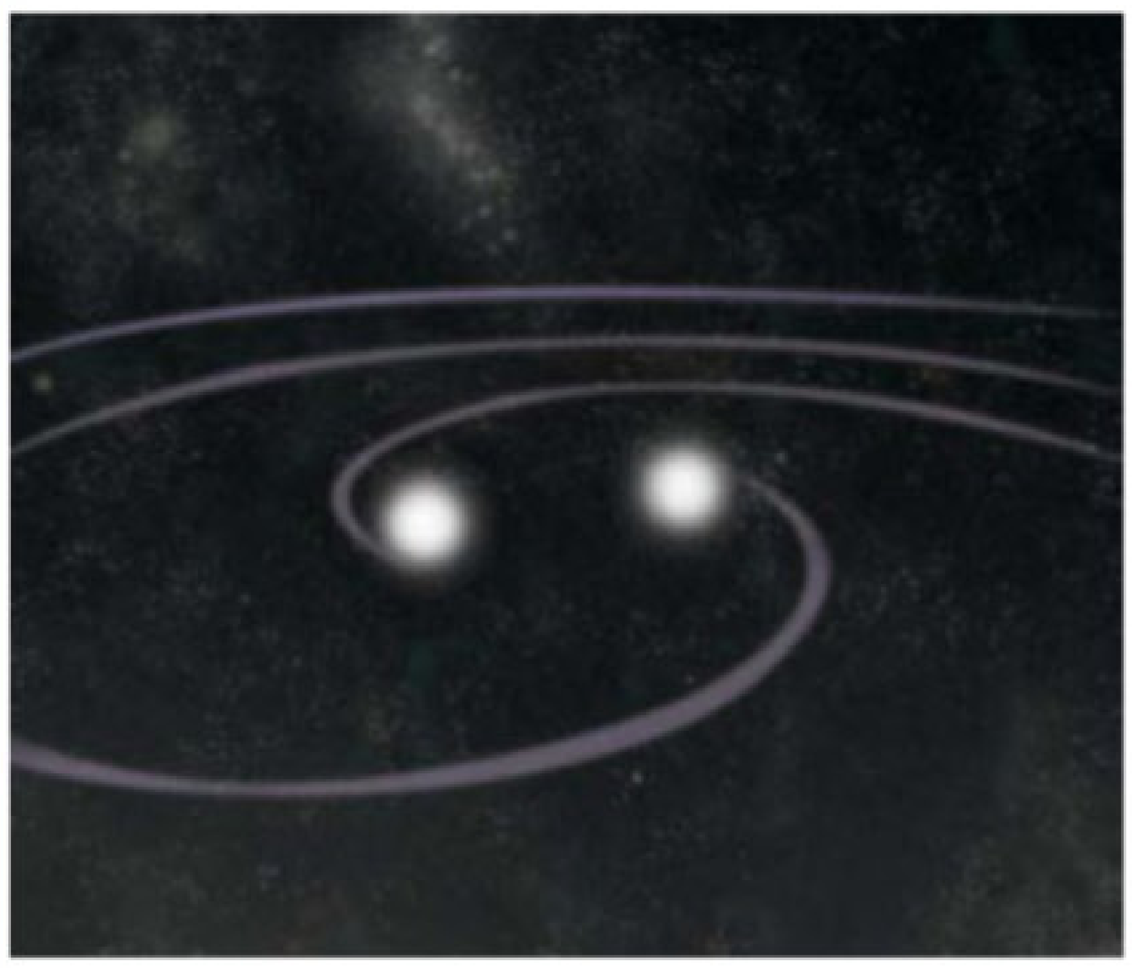
This can be a dance to the death, though. If their orbits are perturbed, perhaps by the changing gravitational field of the red giant before it disappeared, the white dwarfs can start to spiral into one another. As they get closer and closer they begin to unleash gravitational waves, which are ripples in the fabric of space disturbed by the proximity at which these two dense partners are dancing. They get closer and closer until they suddenly crash into each other and spark another supernova.

This won't happen to the Sun's white dwarf, however, because our star doesn't have a stellar companion that we know about. Instead, it will live out the rest of time lonely, slowly cooling from hundreds of thousands of degrees, over thousands of trillions of years. Eventually the star will get so cold that it won't glow at all, becoming a dark, inert lump of dead stellar material called a black dwarf.

The black dwarf is only theoretical at this moment in time, because the universe isn't old enough for even the most ancient white dwarfs to have cooled to become one yet. To put this in context, the Sun's white dwarf will become a black dwarf in a quadrillion years, or one thousand trillion years. This

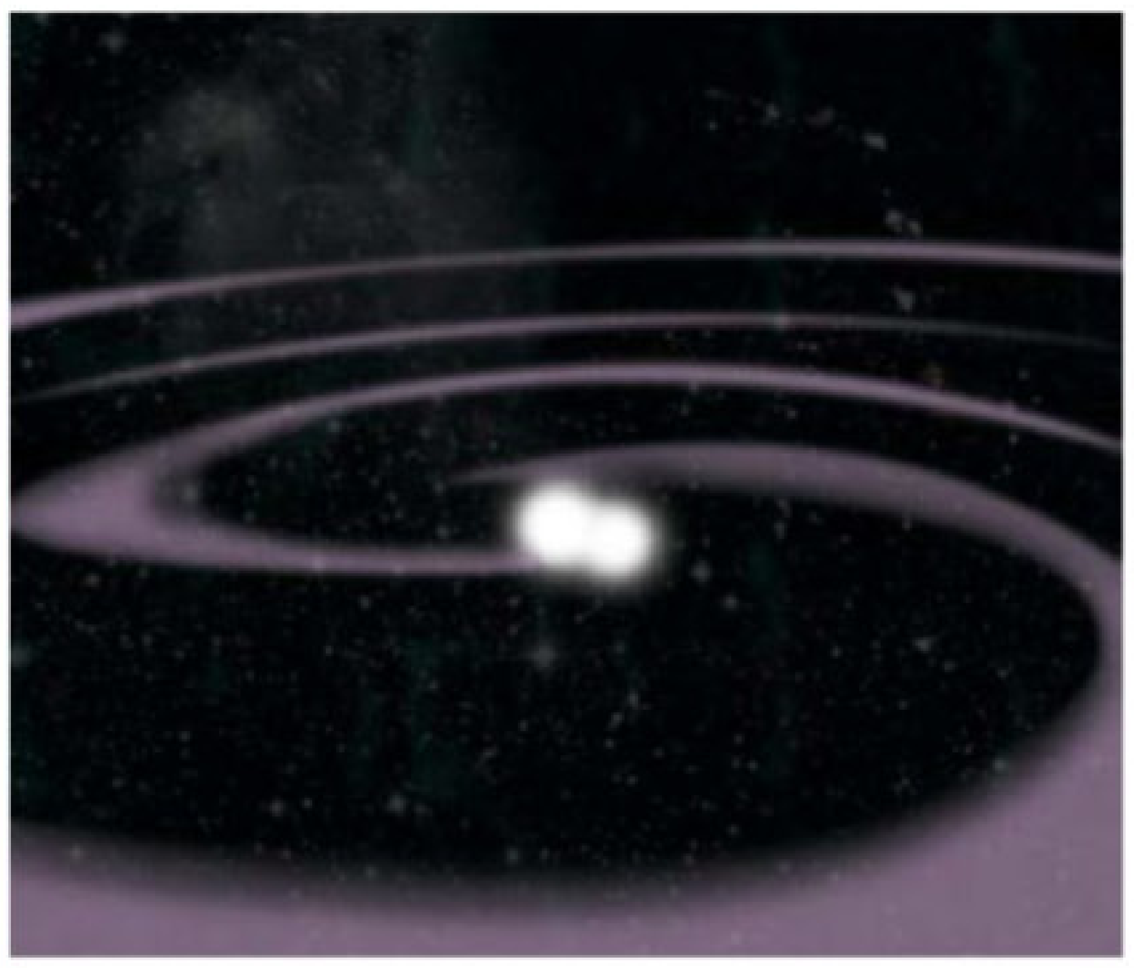
NGC 6751 has a white dwarf and rests 6,500 light years away

When white dwarfs collide



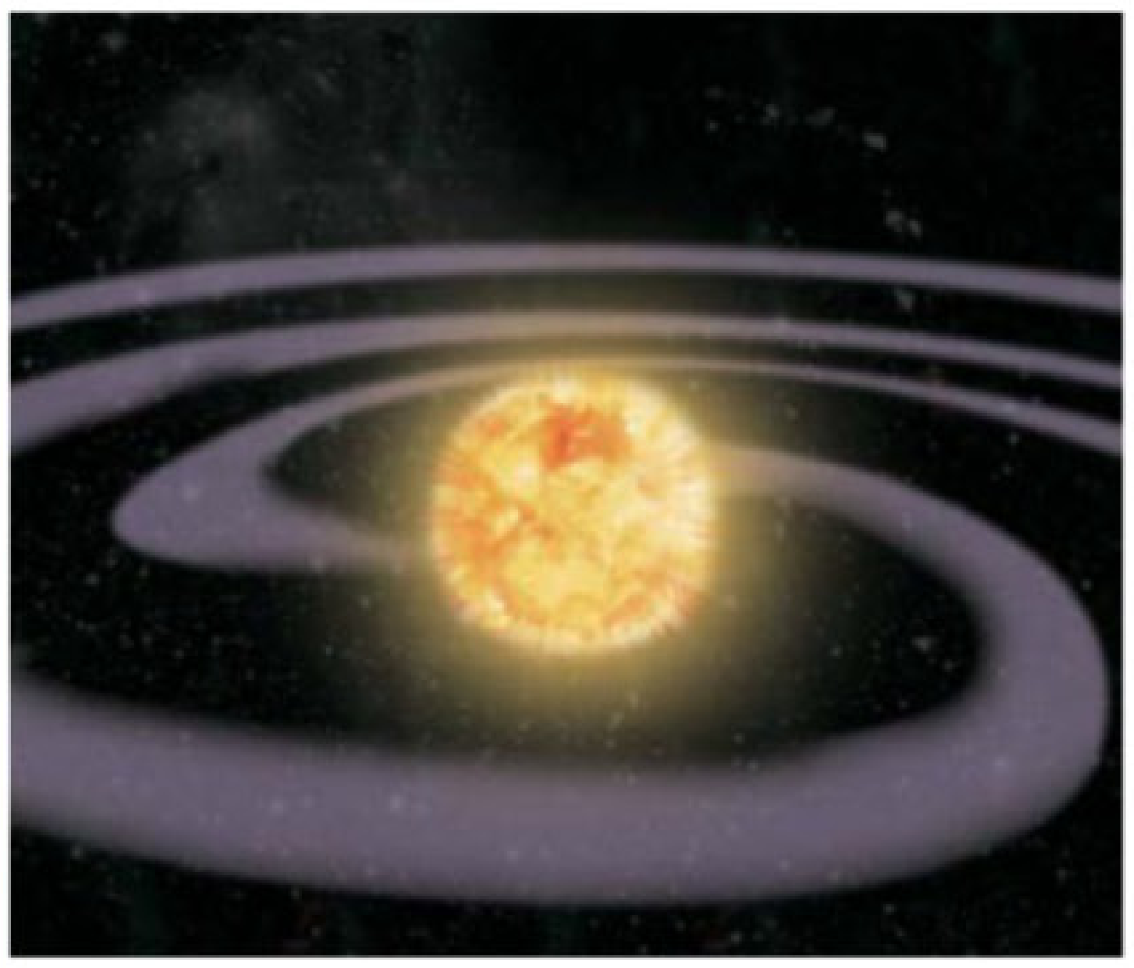
Kicking up waves

When a pair of white dwarfs steadily spiral towards each other, they churn up the sea of space-time. This creates gravitational waves that become more and more intense as the stars accelerate faster.



Ready to merge

As they speed up, the white dwarfs' orbits shrink, bringing them closer together. As they steadily spiral inward, they churn the sea of space-time further and release more gravitational waves.



A great collision

If a pair of white dwarfs are 80,500km (50,000mi) apart, for instance, it will take thousands of years for them to merge. When they meet, a great explosion, such as type-Ia supernova, will occur.

Scientists are currently searching for planets around white dwarfs, however, so far they have only found asteroids orbiting these ancient stars

NASA's Hubble Space Telescope uncovered a collection of ancient white dwarf stars in 2002

is an amazingly long time even in any interpretation - a figure of 1 with 15 zeros after it.

Of course, the Sun's white dwarf will not be completely alone, because it will still have what is left of the Solar System to accompany it in its advanced years. Mercury, Venus and probably Earth will be long gone, a distant memory consumed by the growing red giant that the Sun will evolve into. As the red giant continues to swell, its changing gravitational field will also stir up the planets and the asteroids, causing them to crash into one another, creating an immeasurable amount of debris. All of this planetary debris will linger long after the white dwarf has revealed itself from inside the red giant, when planetary nebulae and asteroids will start to come crashing down into it.

We know this because astronomers have already detected asteroids crashing into white dwarfs. In 2009 scientists used the infrared eyes of NASA's Spitzer Space Telescope to study six white dwarfs and found the chemical imprint of asteroid material in their light. These asteroids were being pulled apart, broken up into dust by the jostling action created by the white dwarfs' gravity. "If you ground up our asteroids and rocky planets, you would get the same type of dust we are seeing in these star systems," says Michael Jura from the University of California, Los Angeles. "This tells us that the stars have asteroids like ours - and therefore could have rocky planets."

In 2013 astronomers at the University of Cambridge used the Hubble Space Telescope to find asteroidal material actually polluting the surface of white dwarf stars in the Hyades star cluster 150 light years away in the constellation Taurus. The astronomers detected the chemical fingerprints of carbon and silicon at ultraviolet wavelengths. These elements are the building blocks of rocky planets and are very commonly found in asteroids.

If asteroids can survive the death of a star, at least until they fall onto the white dwarf and are pulverised, can planets also be found around white dwarfs? "When these stars were born, they built planets and there's a good chance that they currently retain some of them," explains Jay Farihi who was the leader of the 2013 study. "The signs of rocky debris we are seeing are evidence of this - they're at least as rocky as the most primitive terrestrial bodies in our Solar System. Based on the silicon-to-carbon ratio we found, we can actually say that this material is basically Earth-like."

Even if rockier planets are destroyed during the red giant phase of a star, some astronomers still think that new worlds could form from the debris of the planetary nebula. The fate of any outer planets that manage to survive a red giant phase is unclear.

So far astronomers haven't discovered any planets around white dwarfs, but there is a race among competing teams to be the first to find one. If a planet could be found in the habitable zone around a white dwarf, where the temperature would be just right for liquid water - this would have to be very close to the white dwarf - it is possible that something could live on that planet. If this turns out to be the case, it would have many implications for our understanding of the universe's future - proving once and for all that there is life after stellar death.

"As the red giant continues to swell, its changing gravitational field will also stir up the planets and the asteroids, causing them to crash into one another"

Professor Subrahmanyan Chandrasekhar showed that low-mass stars collapse in on themselves after their fuel has run out to form white dwarfs

An artist's impression of the RS Ophiuchi binary system shortly after the white dwarf has exploded as a nova next to its red giant companion

White dwarfs by numbers

9,000

Over 9,000 white dwarfs have been found by the Sloan Digital Sky Survey.

5 tons

A teaspoon of white dwarf star material would weigh as much as an elephant on Earth, at 5 tons.

13.8 billion years

It takes longer than this for white dwarfs to become cold black dwarfs. This end point of a white dwarf is due to it cooling down. However, they are hypothetical and we're very unlikely to see one.

200,000°C

White dwarfs are at least this temperature before they begin to cool down.

97%

The number of stars in the Milky Way that will become white dwarfs at the end of their lives.

1.4 solar masses

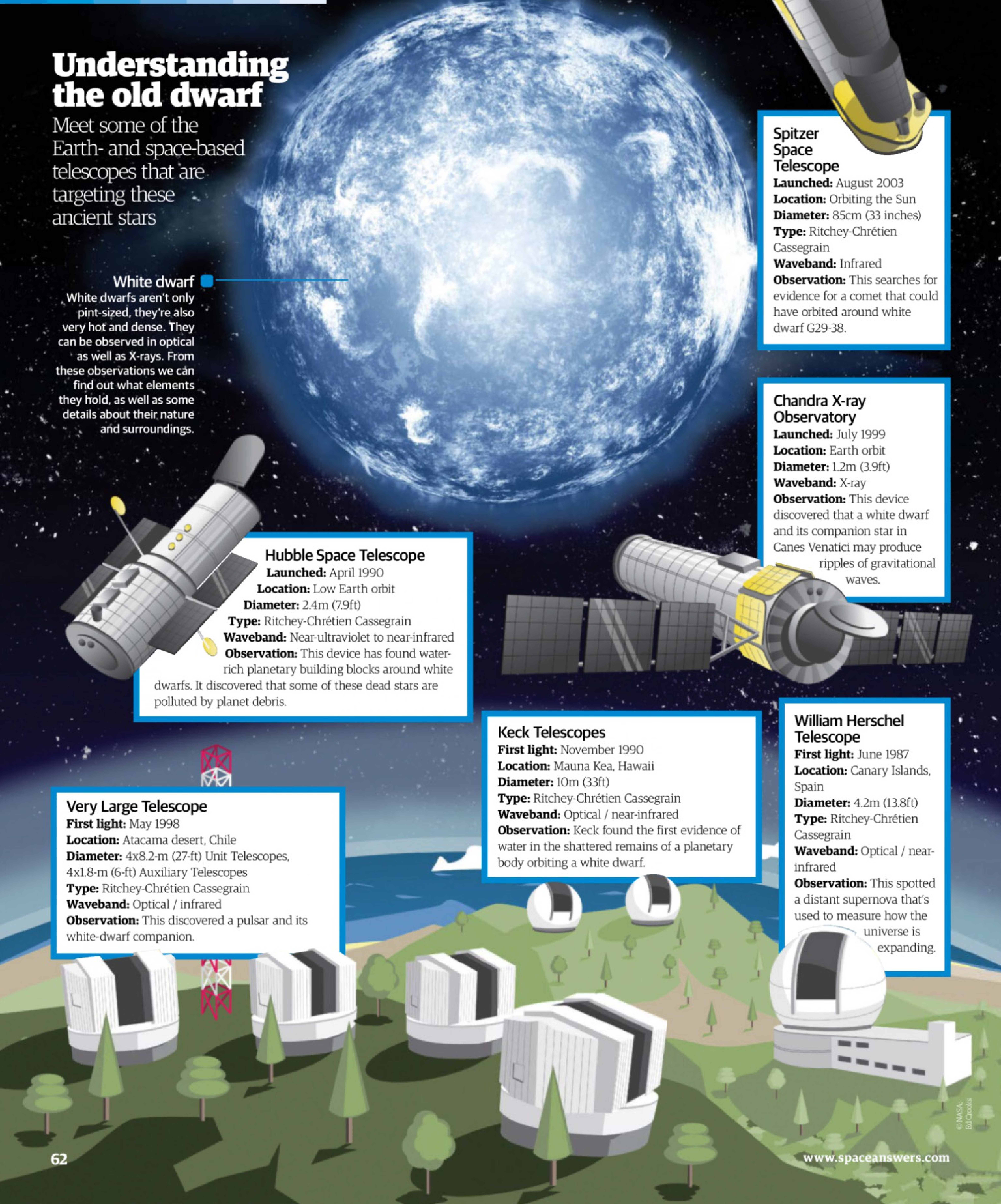
The mass a white dwarf can be - if it exceeds this extent, called the Chandrasekhar limit, it'll explode as a big type-Ia supernova.

1783

The year William Herschel spotted a white dwarf for the first time, named 40 Eridani B.

Understanding the old dwarf

Meet some of the Earth- and space-based telescopes that are targeting these ancient stars



White dwarf

White dwarfs aren't only pint-sized, they're also very hot and dense. They can be observed in optical as well as X-rays. From these observations we can find out what elements they hold, as well as some details about their nature and surroundings.

Spitzer Space Telescope

Launched: August 2003
Location: Orbiting the Sun
Diameter: 85cm (33 inches)
Type: Ritchey-Chrétien Cassegrain
Waveband: Infrared
Observation: This searches for evidence for a comet that could have orbited around white dwarf G29-38.

Chandra X-ray Observatory

Launched: July 1999
Location: Earth orbit
Diameter: 1.2m (3.9ft)
Waveband: X-ray
Observation: This device discovered that a white dwarf and its companion star in Canes Venatici may produce ripples of gravitational waves.

Hubble Space Telescope

Launched: April 1990
Location: Low Earth orbit
Diameter: 2.4m (7.9ft)
Type: Ritchey-Chrétien Cassegrain
Waveband: Near-ultraviolet to near-infrared
Observation: This device has found water-rich planetary building blocks around white dwarfs. It discovered that some of these dead stars are polluted by planet debris.

Keck Telescopes

First light: November 1990
Location: Mauna Kea, Hawaii
Diameter: 10m (33ft)
Type: Ritchey-Chrétien Cassegrain
Waveband: Optical / near-infrared
Observation: Keck found the first evidence of water in the shattered remains of a planetary body orbiting a white dwarf.

William Herschel Telescope

First light: June 1987
Location: Canary Islands, Spain
Diameter: 4.2m (13.8ft)
Type: Ritchey-Chrétien Cassegrain
Waveband: Optical / near-infrared
Observation: This spotted a distant supernova that's used to measure how the universe is expanding.

Very Large Telescope

First light: May 1998
Location: Atacama desert, Chile
Diameter: 4x8.2-m (27-ft) Unit Telescopes, 4x1.8-m (6-ft) Auxiliary Telescopes
Type: Ritchey-Chrétien Cassegrain
Waveband: Optical / infrared
Observation: This discovered a pulsar and its white-dwarf companion.

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An animal in crisis

In eastern Africa, poachers use automatic weapons to slaughter endangered rhinos. The animals are shot and the horns are hacked away, tearing deep into the rhinos' flesh with the rhino left to die.

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Ol Pejeta is a leading conservancy fighting against this cruelty. It needs more funds so more rangers and surveillance can be deployed on the ground to save rhinos from this horrible treatment.

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World of Animals magazine takes a stand against these atrocities and is proud to be in partnership with the Ol Pejeta Conservancy – 10% of our profits go towards saving rhinos in the fight against poaching

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What is the Drake equation?

How many intelligent civilisations are there in the galaxy? Frank Drake's formula is both simpler and more complicated than it looks

In 1961 astronomer and astrophysicist Frank Drake, future founder of the SETI Institute (the Search for Extra Terrestrial Intelligence), constructed an equation designed to estimate the number of intelligent civilisations there are in the Milky Way. It brought together seven variables he thought were key to this formula, although it wasn't intended as an absolute solution. Rather, Drake had created what would come to be known as the Drake equation to prompt discussion at a meeting with space professionals, concerned with the search for extraterrestrial intelligence, .

As a means of calculating an exact value of intelligent extraterrestrial civilisations, it's deeply flawed. While powerful space telescopes and exoplanet observations in recent years have enabled astronomers to narrow down the first three variables, the latter four concerning the conception of life, evolution and intelligence are either difficult or impossible to tell.

With our current knowledge, a solution using this equation would put the number of intelligent extraterrestrial civilisations in the galaxy in the range of anything from zero to billions – not a very useful figure at all. However, as a way of promoting scientific thought and summarising what might constrain SETI's, if not the space industry's efforts to search for life, it's been very successful. The fact the Drake equation has endured 50 years and is still famous, is testament to that.

R^* x f_p x n_e x f_l x

Number of stars

The first parameter in the Drake equation estimates the average rate of star formation in the galaxy. Our galaxy produces around seven new stars every year, although in its youth it would have created 100 or more. The basic equation doesn't take into account the type of star: systems with short-lived, massive and hot stars are hostile to life.

Stars with planets

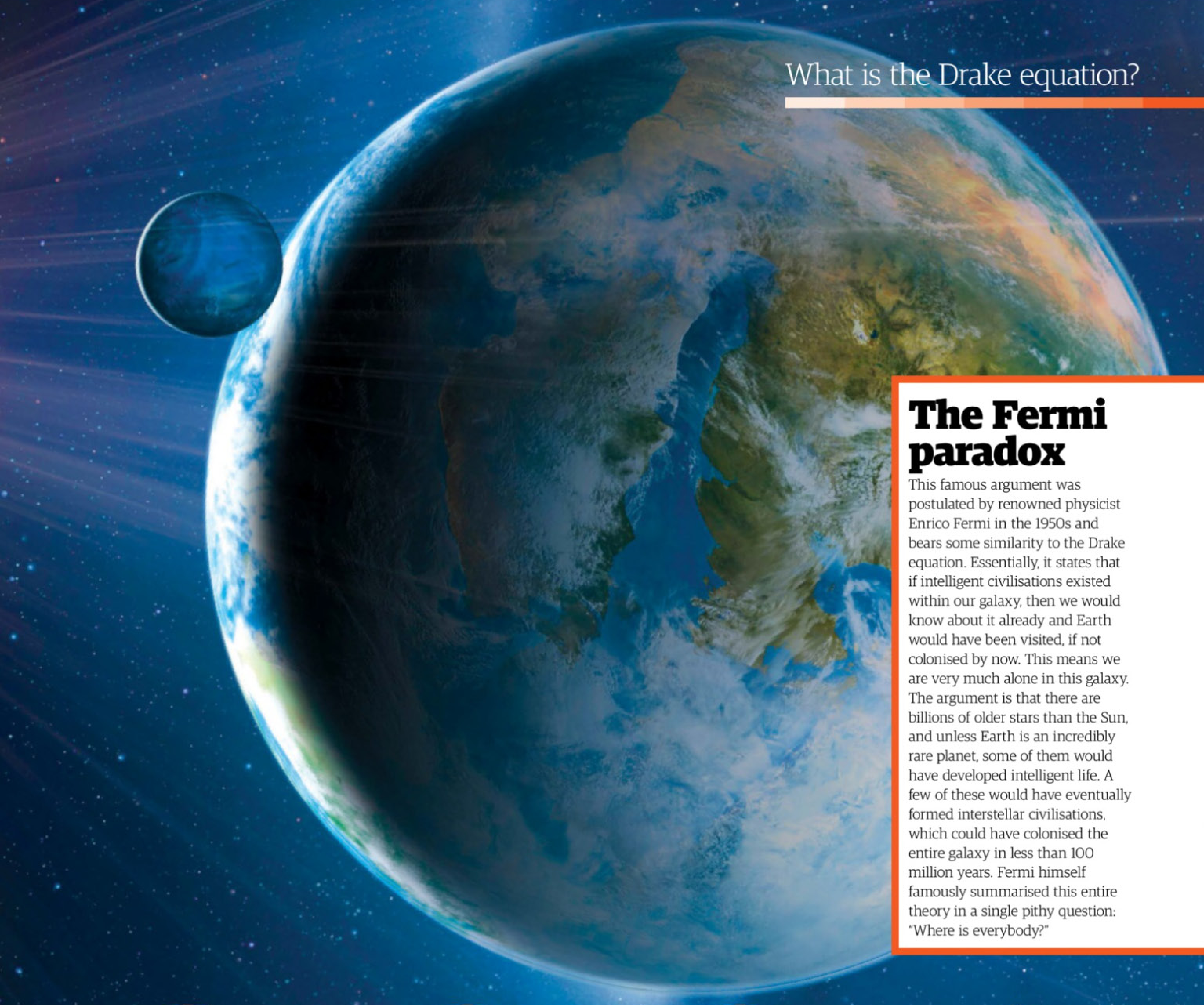
This calculates the fraction of those star systems that host planets. When the Drake equation was formulated the only known planets were in our own Solar System. Today, we know of nearly 2,000 exoplanets and it's thought that, on average, there's at least one planet for every star in our galaxy, putting this number in the hundreds of billions.

Habitable planets

We've got a good idea of this part of the equation, which calculates the average number of planets capable of supporting life for every star that has planets. Drake gave this parameter an optimistic value of two, meaning two Earth-like worlds for every star with planets. Today we think one in five Sun-like stars has a planet that can support life.

Supports life

This is where the equation begins to fall apart. Because Earth is the only place in the universe where we know life has occurred, it's difficult for scientists to determine how easily life can form on other habitable planets. If we can find evidence of past life in our Solar System, we'll be more able to assign this parameter a more-accurate value.



The Fermi paradox

This famous argument was postulated by renowned physicist Enrico Fermi in the 1950s and bears some similarity to the Drake equation. Essentially, it states that if intelligent civilisations existed within our galaxy, then we would know about it already and Earth would have been visited, if not colonised by now. This means we are very much alone in this galaxy. The argument is that there are billions of older stars than the Sun, and unless Earth is an incredibly rare planet, some of them would have developed intelligent life. A few of these would have eventually formed interstellar civilisations, which could have colonised the entire galaxy in less than 100 million years. Fermi himself famously summarised this entire theory in a single pithy question: "Where is everybody?"

$$f_i \times f_c \times L = N$$

Intelligent life

If estimating the regularity of life occurring on habitable worlds in our galaxy is tough, then estimating the emergence of intelligent life is near-impossible. Life on Earth took around a billion years to emerge, but complex life was slower to evolve. Drake thought just 1 in 100 planets with life in the galaxy would go on to evolve sentient species.

Detectable life

There are a number of signs of extraterrestrial life that organisations like SETI look for, but they search for repeating patterns in radiowaves. The limitations of this form of communication are one reason why we haven't ever detected this kind of signal, but Drake thought that one in 100 civilisations would have the technology.

Detectable period

Extraterrestrial civilisations with interstellar communication may have existed or could exist in our galaxy, but we may either have missed their signals or won't be around to detect them in the future. Estimates for this parameter are upwards of 50 years, although Drake guessed a civilisation might remain detectable for 10,000 years.

Possible communication

Now we arrive at the solution: the number of civilisations in the Milky Way with which communication may be possible. The variability in each of the parameters that lead to this figure makes any hard solution from the equation an exercise in futility. It's a tangible way to communicate and educate people about the search for life, however.

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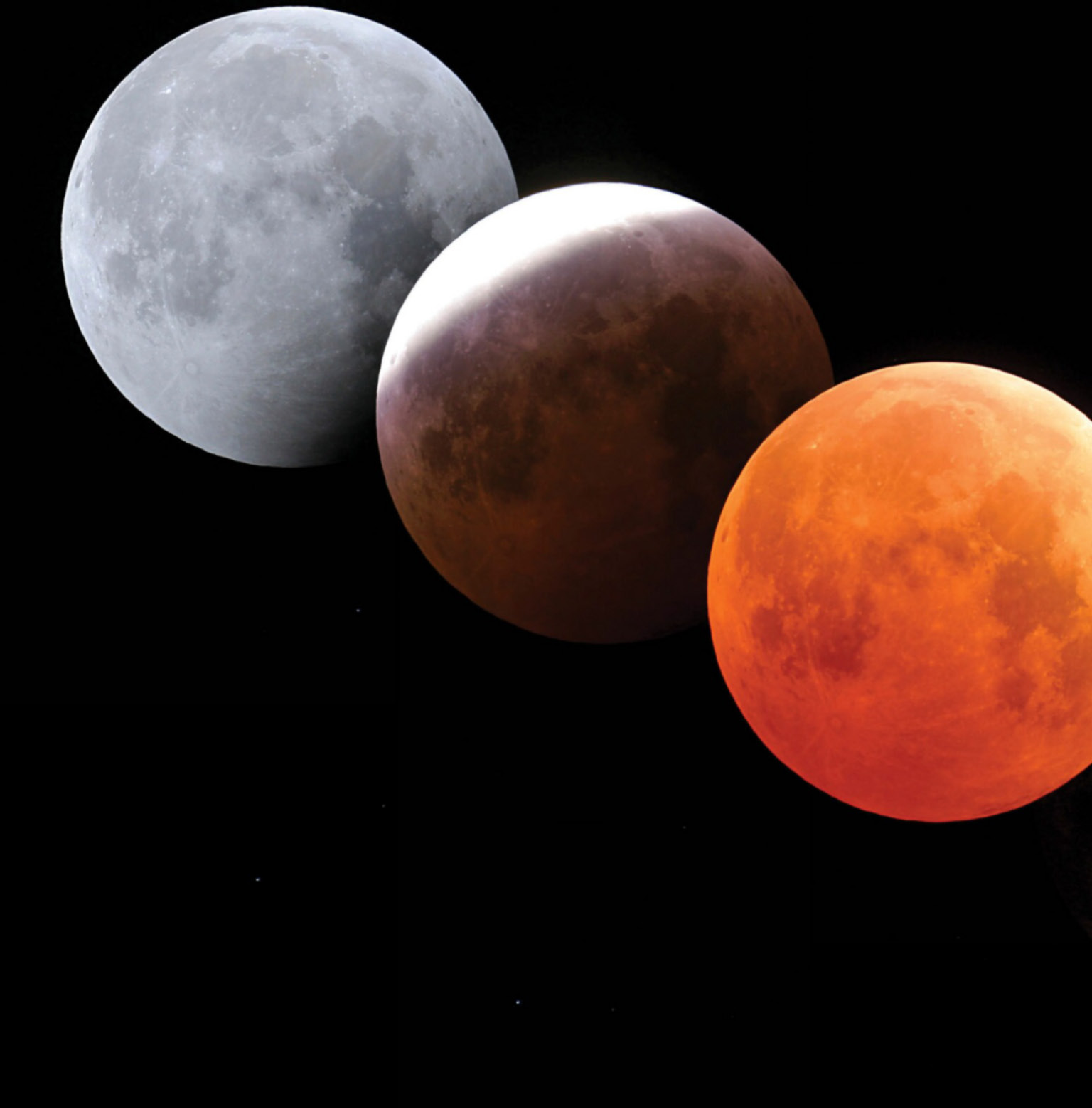


A lunar eclipse is also referred to as a blood Moon due to its crimson colouring that's created by the Sun's light. This light filters through the Earth's atmosphere when the Moon is in our planet's shadow

Blood Moon

What causes our satellite to turn this ruddy shade?

The Moon is Earth's companion in space. It's a night-sky object that's hard to miss as it reflects sunlight from its grey and barren soil, shining white like a battery-operated torch on the blooming and fertile soils of our planet. That's until it begins to turn red.

You might have seen a so-called blood Moon before, as the lunar surface gradually shifts through progressive shades of crimson. Scientifically this is called a total lunar eclipse and it's the positioning of the Sun, our planet and the Moon that's responsible for the eye-catching difference in colour.

To imagine what happens during one of these events, picture the Sun, Earth and Moon in a line and in that order. Remember that, given our lunar companion is much smaller than Earth, any great amount of light trying to reach it from our star will be blocked out by our planet's bulk. This means our natural satellite is forced to remain in its shadow. However, not all rays of light are deterred by the lineup - a few manage to sneak through to beam onto the lunar land.

This visible light, made of a spectrum of different wavelengths, has battled its way through Earth's atmosphere. It doesn't get through unscathed - most of the blue light is filtered out and deep-red or orange rays of light are left that are much dimmer.

With Earth's atmosphere toying with some of the visible light by bending or refracting it, a small band of longer wavelength red makes its way to the lunar surface, painting our companion crimson. ●

© Alamy

Spilker at the Goldstone Deep Space Communications Complex in the Mojave Desert, California

Ten years at Saturn

The Cassini spacecraft celebrates a decade since it entered orbit around Saturn this July: All About Space spoke with project scientist Linda Spilker about the orbiter's highlights

Interviewed by Ben Biggs

INTERVIEWBIO

Linda J. Spilker
Beginning her career at NASA in 1977, Spilker has devoted nearly 40 years to high-profile space missions such as Voyager and Cassini-Huygens. She's received numerous scientific awards for her work, most recently a NASA Exceptional Service Medal in 2013.

It's been ten years since Cassini arrived at Saturn. What has the highlight of this mission been for you?
I think there have been two main highlights. They were the discovery of the jets coming out of the south pole of the tiny moon Enceladus and the recent detection that there's actually an ocean underneath the south pole. It's an intriguing thing that there's a liquid reservoir in contact with a rocky core, so we have all the ingredients for possible life, in a habitat in the outer Solar System that's very different from what we typically think of as a habitat.

That was my most exciting highlight recently, then of course there was landing the Huygens probe on the surface of Titan. It actually pierced through the haze and we had a real sense of unveiling what Titan's surface looks like.

Is it probable that Cassini could find life beneath the surface of Enceladus, another of Saturn's orbiting moons?
Well, I think that it's certainly a habitat and that possibility is very intriguing. [Analogies with Earth include] the hydrothermal vents in the ocean that get no sunlight, but there's life all around them. You can't help but wonder if something similar has happened on Enceladus.

If a habitable environment were found there, how would that reflect on the possibility of life in the Milky Way?
We'd certainly have to expand to think of places that could possibly host life. Also in the Saturn system there's Titan, which we think has a global ocean of liquid water beneath a thick icy crust, and then there's Jupiter's Europa. Here we have at least three places in the Solar System, very different from Earth, where we might find life…

> "There's a liquid reservoir in contact with a rocky core, so we have all the ingredients for possible life"

Huygens today remains the furthest lander from Earth. When do you think we'll next have an opportunity to land outside the Solar System?
I know we have the Rosetta mission that's on its way to a comet and it actually has a lander that will land on the comet's surface. That's coming up soon, this year – that will be the next landing on a world far from the Sun.

We've learned much about Saturn during Cassini's orbit and it has provided us with some of the most spectacular space images yet. What have we learned about the Solar System in general from Cassini?
You're right in that. If we think of Saturn and its rings as a miniature Solar System, its rings are an analogy for a dusty disc and we see moons form in them, which is like planets forming around a star. We've been watching these objects that are too small to see, but they create these structures called propellers, with these two arms around them. These propellers enable us to estimate the sizes of these objects and

Titan IV with Cassini-Huygens launches with Liberty Star in the foreground very recently there's been evidence of an object just on the outer edge of Saturn's A-ring, which we've named Peggy. Maybe that object, Peggy, will break free and become a new moonlet.

This would give us a better idea of how satellites around other planets form?

How satellites [in general] would form, and it's analogous to how planets would form in a dusty disc – or at least, the planetesimals that would go on to form planets.

Cassini launched 17 years ago and is part-way through its second mission extension that will end in 2017 – could it go on for longer?

We're ending the mission in 2017 because basically we're starting to run out of fuel – the mono- and bi-propellant that enables us to turn and target the spacecraft. So for planetary protection of the two worlds Enceladus and Titan, which could possibly have a liquid water ocean, we want to make sure we don't accidentally run out of fuel and run into one of those. A good way to not impact Titan or Enceladus and have a brand-new mission at the end as well, is to have 22 orbits that will dive in between the top of Saturn's atmosphere. At the end of 22 orbits we'll get a slight nudge from Titan's gravity that actually puts us into Saturn and Cassini will end up vaporised by Saturn's atmosphere. It's very similar to what happened to Galileo.

> "At the end of 22 orbits we'll get a slight nudge from Titan's gravity that actually puts us into Saturn and Cassini will end up vaporised by Saturn's atmosphere"

As Cassini plunges into Saturn and gets crushed, will it be able to return images?

In those 22 orbits we'll get some unique science – science that we can't currently do. This includes some really exquisite measurements of Saturn's gravity field and magnetic field that will tell us about the internal structure of Saturn, what kind of core it has and how deep the circulation at the top of Saturn goes into its interior. We could also get the mass of the rings for the very first time – that's really important to understand the age of the rings. Uncertainty of the rings' masses right now is about 100 per cent… which means we really don't have a good idea about their total mass. If they're much more massive than we think, then it's possible that Saturn's rings were formed at the same time as Saturn and are about four billion years old. If they're less massive, then they might have formed by meteorites coming too close and being torn apart by the gravity of Saturn.

How can you tell the mass of the rings by sending Cassini into Saturn?

It's not so much by plunging into Saturn, but during those 22 orbits we'll measure its gravity field, then be able to calculate the mass of Saturn and using that, the mass of its rings. When we plunge into the atmosphere, we'll probably turn the high-gain

One of the most-celebrated space photos in history: the Cassini imaging team made this spectacular mosaic of Saturn, backlit by the Sun, from 165 high-resolution images antenna to the Earth to send back data as we plunge through the atmosphere. This will happen very quickly – it will really be in the orbit before, that we'll have a chance to get really high-resolution pictures of the rings. The same goes for the atmosphere of the planet – we'll get high-resolution pictures of Saturn itself. We'll keep sending back data and see if we can get more and more information about the composition of the atmosphere of Saturn as we go lower and lower. We have an Ion and Neutral mass spectrometer sending back data… and who knows? We may turn the cameras on and try to get a good attitude just until the atmosphere turns the high-gain antenna away from the Earth.

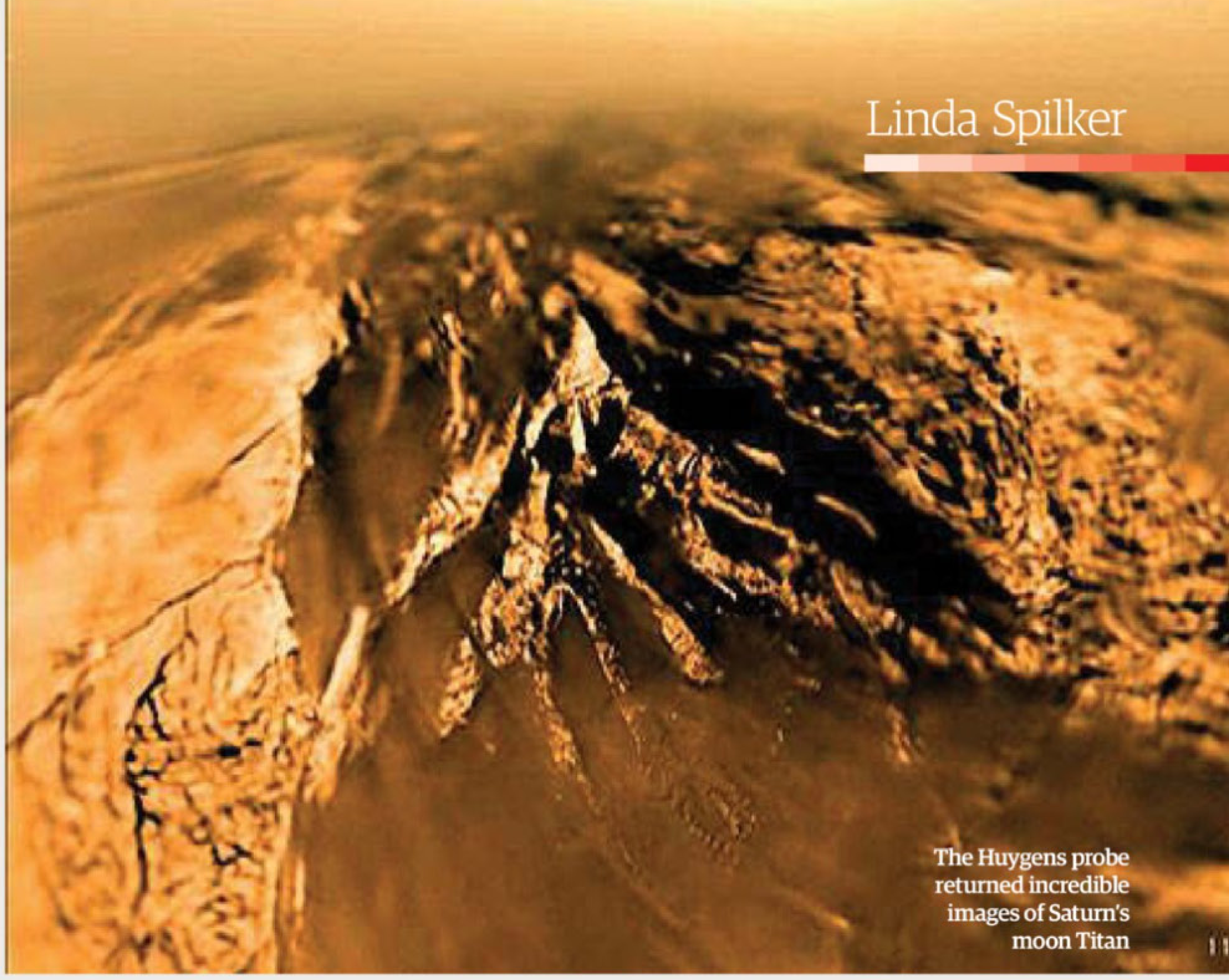
So we'll have some images at the end to rival what we've seen so far?
Oh, absolutely. Whenever you get higher resolution it's always intriguing to see what you might get in the rings or what you might further discover about Saturn's atmosphere.

End-game aside, what kind of science can we expect from Cassini, from now until 2017?
It takes Saturn about 30 years to orbit the Sun a single time and by the end of Cassini it will almost be at the end of a single Saturn season. So in the next three years we will be looking for seasonal changes, summer is coming to the north pole of Saturn and Titan in particular. There's a possibility that the wind will pick up and then we will be able to detect waves on some of its seas and lakes. Maybe the lakes will evaporate, maybe clouds will form and it will rain, there could be dry lake beds… we're just going to watch as the seasons change. On Saturn we'll see if any new storms start and now we'll have a really good view of this hexagonal-shaped jet stream at Saturn's north pole. It's so amazing that you could have a jet stream so precisely shaped. We'll also be looking at the rings as the Sun will be at its highest angle ever and shines down on them. There are three more close fly-bys of Titan and Enceladus and one of them will look at the north pole of Enceladus and get the highest-resolution pictures ever of this region.

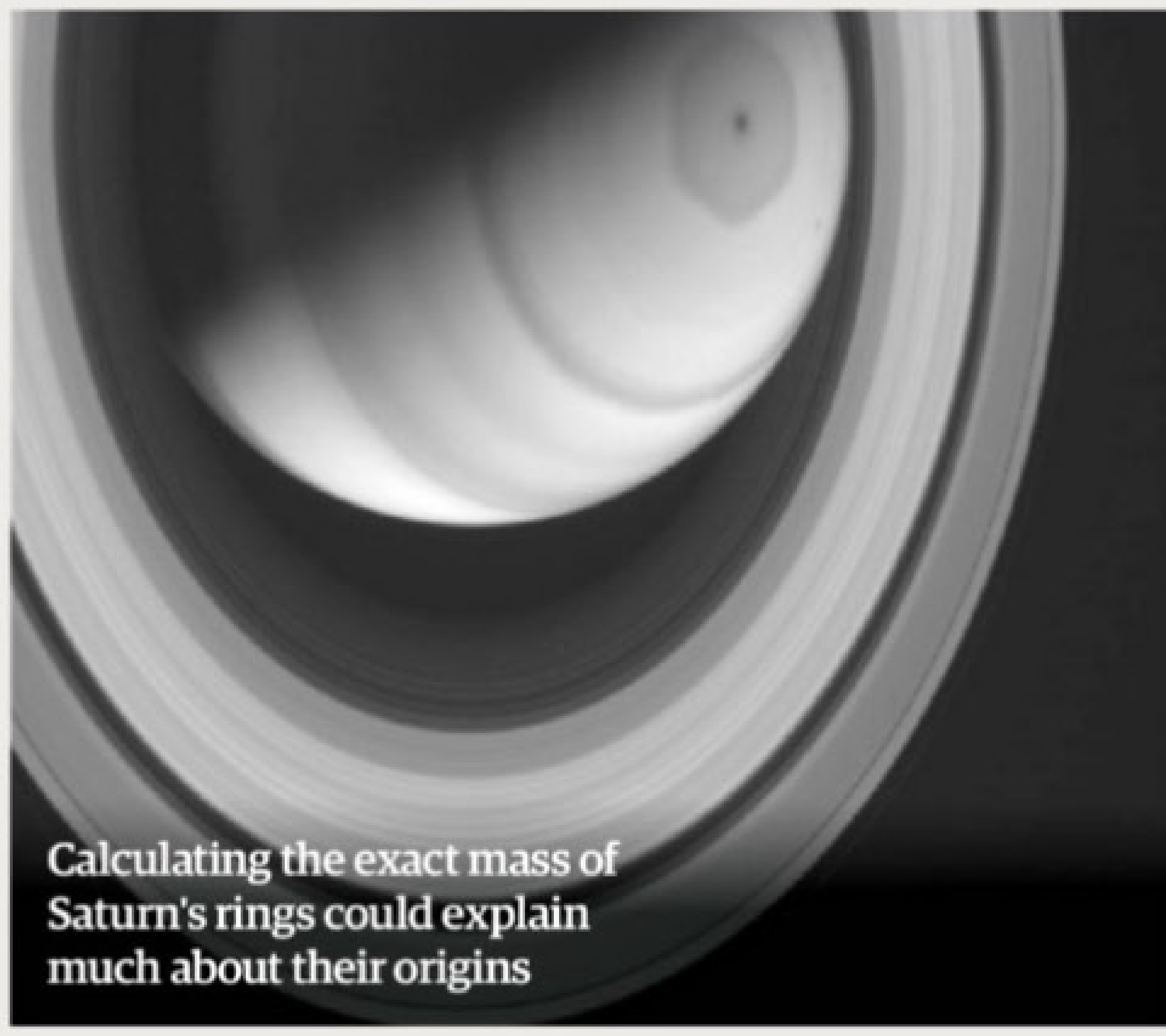
Is there any correlation between the Saturn Hexagon and Jupiter's Great Red Spot?
Voyager first saw the Hexagon in the early 1980s and it's a little bit different in that it's more of a jet stream. The Great Red Spot is more like a hurricane… and it looks like it's shrinking! I thought that was pretty interesting, maybe we'll see it disappear.

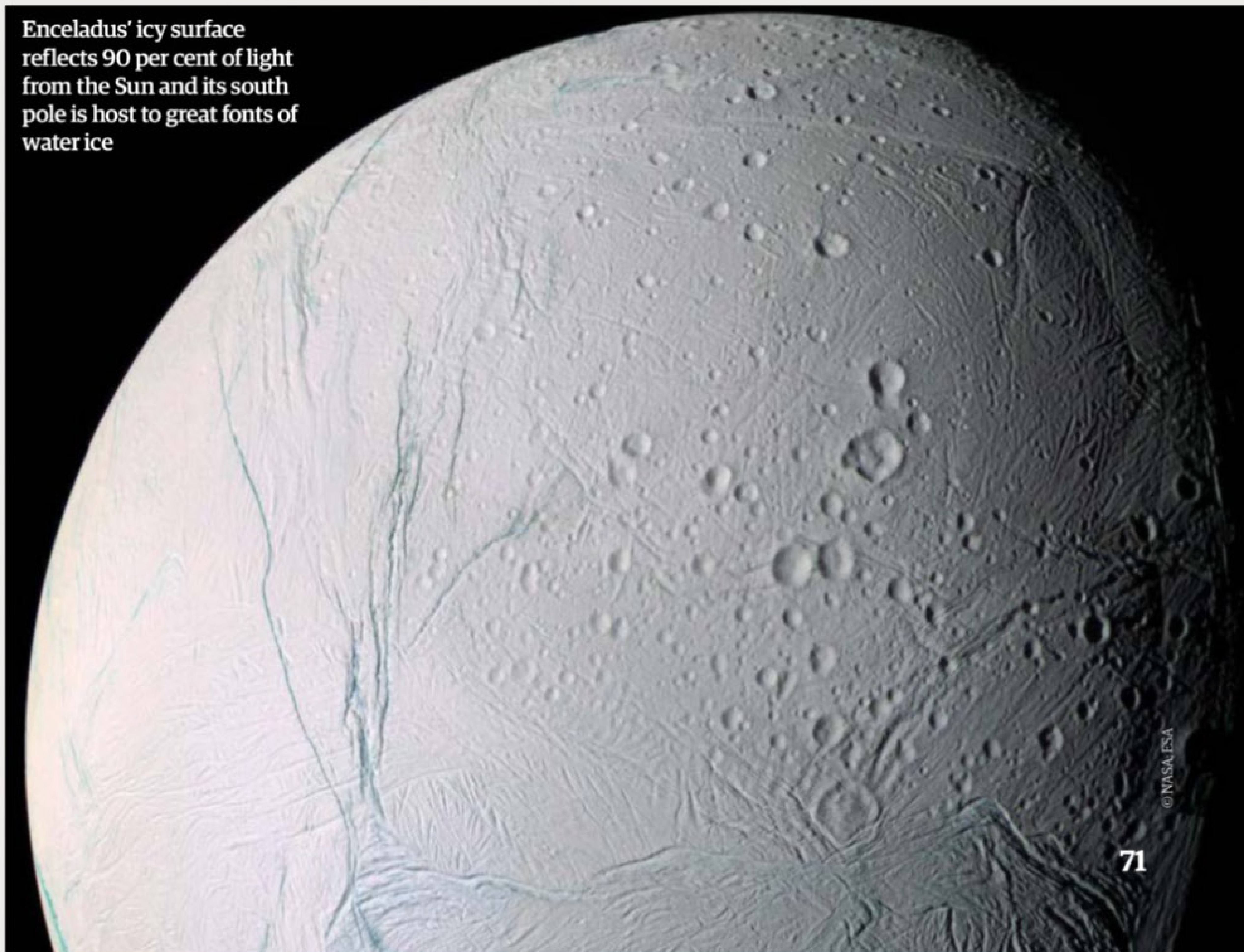
You've come out of the Cassini Senior Review last week, how did it go?
I can't say a lot about it, but Cassini was one of several current missions that had to present material. The review is over and I think it went well.

You've been involved in two high-profile space missions in your career, Voyager and Cassini. Do you have a favourite?
That is really a tough question. Given how long Cassini's been in the Saturn system I would probably pick Cassini, but it's a tough choice because Voyager has visited four different worlds… but it's Cassini just by a nose.


The Huygens probe returned incredible images of Saturn's moon Titan

Technicians prepare the multi-layered thermal insulation on the Huygens probe


Calculating the exact mass of Saturn's rings could explain much about their origins


Enceladus' icy surface reflects 90 per cent of light from the Sun and its south pole is host to great fonts of water ice

© NASA; ESA

The Bullet cluster

What's the matter with these two colliding galactic clusters?

This concentrated region of galaxies found in the Carina constellation is commonly known as the Bullet cluster and it's one of the hottest galactic collisions found in space.

It's made up of two clusters, the smaller of which passed through the other 150 million years ago, creating a shock wave as gas that was heated to 70 million degrees Celsius (158 million degrees Fahrenheit) passed through even hotter 100-million-degree-Celsius gas (212 million Fahrenheit) at a speed of 9.66 million kilometres an hour (six million miles an hour). The result was an incredible output of energy equivalent to ten quasars.

This composite image shows visible light recorded by the Hubble and Magellan telescopes, plus X-ray emissions (pink) recorded by the Chandra telescope. Dark matter was indirectly observed by the gravitational lensing of objects in the background.

The Bullet cluster is currently the best evidence we have to support the theory of dark matter

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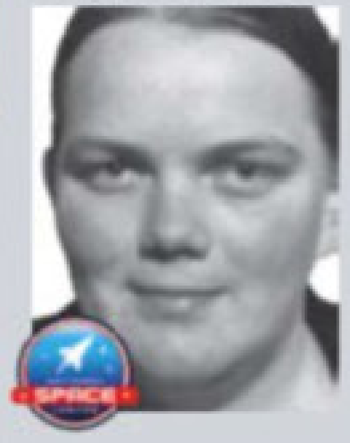
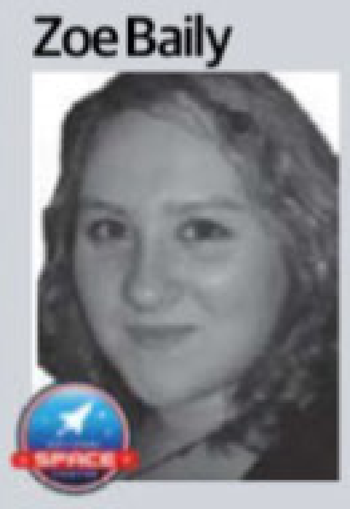
Sophie Allan



National Space Academy Education Officer

■ Sophie studied Astrophysics at university. She has a special interest in astrobiology and planetary science.

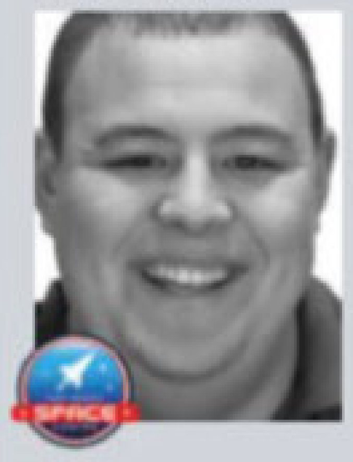
Zoe Baily



National Space Centre

■ Zoe holds a Master's degree in interdisciplinary science and loves the topic of space as it brings together many different scientific disciplines.

Josh Barker



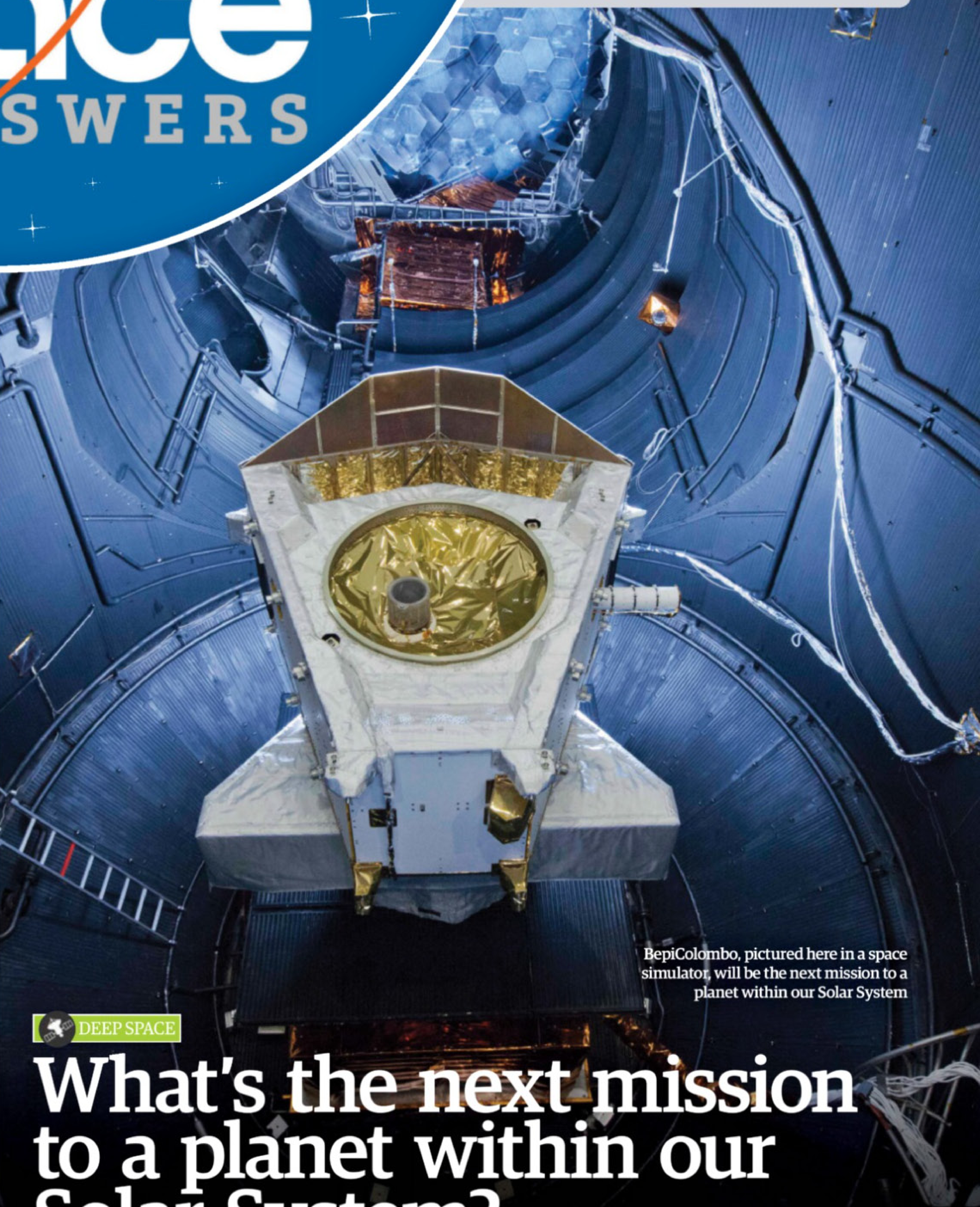
Education Team Presenter

■ Having achieved a Master's in Physics and Astrophysics, Josh continues to pursue his interest in space at the National Space Centre.

Gemma Lavender

Senior staff writer

■ Gemma has been elected as a fellow of the Royal Astronomical Society, is a keen stargazer and telescope enthusiast on **All About Space** magazine.



BepiColombo, pictured here in a space simulator, will be the next mission to a planet within our Solar System

DEEP SPACE

What's the next mission to a planet within our Solar System?

Rolf Cooper

The next mission to be launched to a planet within our Solar System is the BepiColombo mission to Mercury. This is a joint project between ESA and JAXA (the European and Japanese space agencies).

The mission primarily aims to investigate the origin and evolution of the closest planet to the Sun, which we know so little about. It will gather important information about Mercury's geology, composition, magnetic field and atmosphere.

In order to get there, BepiColombo will use a series of gravity-assisted flybys of Earth and Venus in conjunction with an electric ion drive. Due to launch in July 2016, the journey will take eight years before the spacecraft enters orbit. **JB**

Make contact: @spaceanswers /AllAboutSpaceMagazine questions@spaceanswers.com

ASTRONOMY

Are solar telescopes dangerous to use?

Neil Simmons

Solar telescopes aren't dangerous as long as they are used correctly. Clearly looking at the Sun with the naked eye, binoculars or telescopes not designed for solar viewing would be disastrous. Looking at the Sun in this way will almost certainly result in damage to our eyesight and should be avoided at all costs.

Solar telescopes use a series of filters to lower the risk to the eyes. The filter helps lower the intensity of the light from the Sun and by lowering the intensity it's possible to use a solar telescope to investigate the fascinating features of our star safely. **JB**

Provided they're used correctly, solar telescopes are safe to use

SOLAR SYSTEM

Does it snow on Mars?

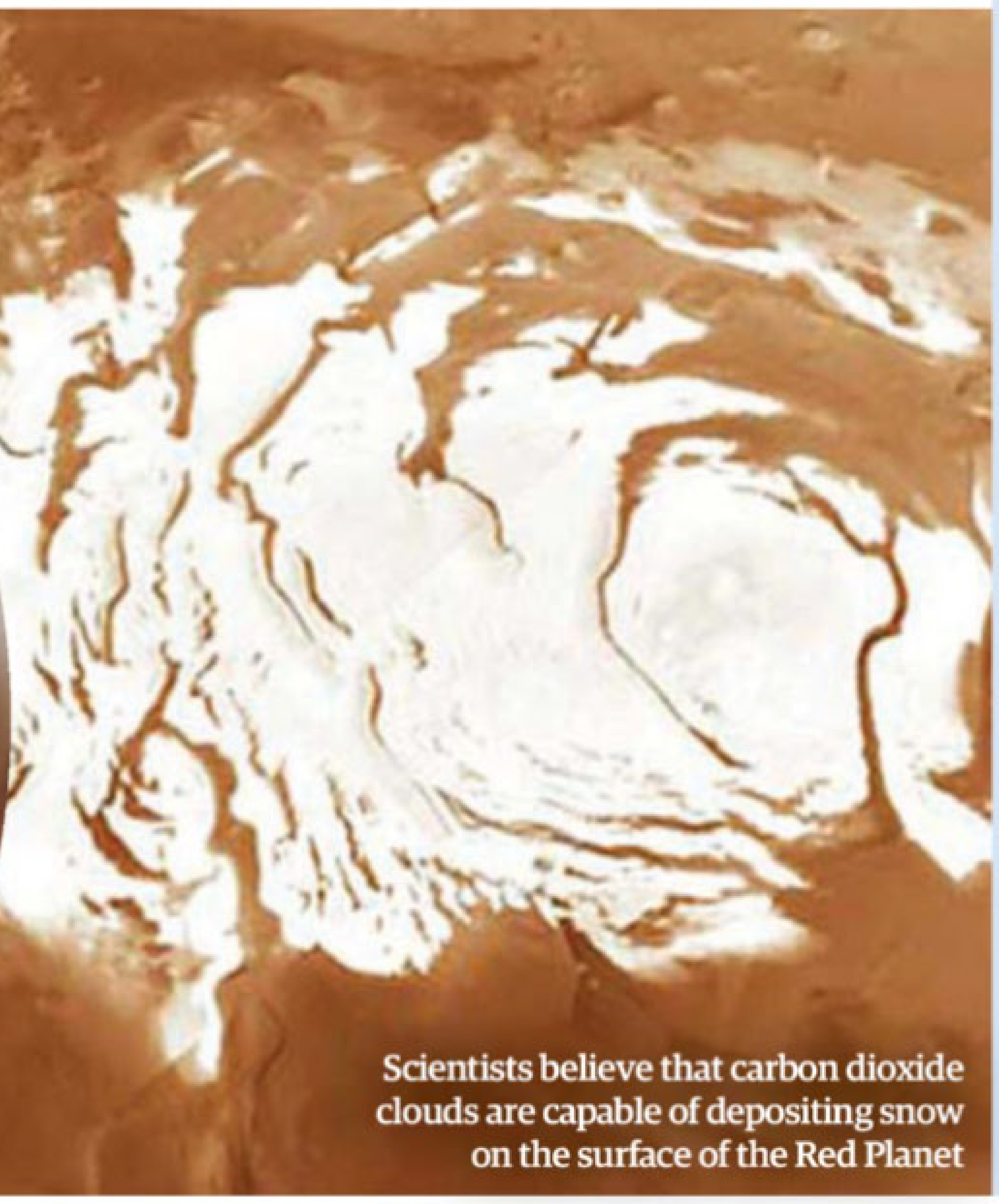
Brian Lawrence

At such cold temperatures, it does snow on Mars – NASA's Phoenix Mars Lander detected snow falling from the Martian clouds back in September 2008. However, before the snow had a chance to reach the ground, it vaporised into streaks called virgae.

Even more-recent studies with the Mars Reconnaissance Orbiter revealed clear evidence that there are in fact carbon dioxide snow clouds. Scientists behind the study revealed that these clouds were thick enough to result in snowfall accumulation on the surface of the Red Planet. Just as water-based snowfalls occur during winter in Mars' northern hemisphere, CO2 snowfalls occur in the planet's southern hemisphere during the south pole's own winter.

Frozen CO2 persists in the southern region all year round, but how it got there is still a mystery. **GL**

An artist's impression of Mars during its ice age over 400,000 years ago, with the caps creeping across the surface



Scientists believe that carbon dioxide clouds are capable of depositing snow on the surface of the Red Planet

The more mass an object has, the greater the affect of gravitational lensing

DEEP SPACE

Why is gravitational lensing useful?

Aaron Bates

Gravitational lensing is an effect described by Einstein's theory of general relativity and works like a magnifying glass, helping astronomers to see objects that are far away – such as galaxies and clusters of galaxies.

The gravitational field of a massive object extends far into space and causes light rays and other radiation passing close to that object to be bent and refocused into a much larger image somewhere else. The more massive an object, the stronger its gravitational field and the more it bends light rays. We can determine many properties of an object that has undergone gravitational lensing – including mass distribution as well as its radius and the distance to it. **GL**

SOLAR SYSTEM

Would we need a spacesuit for interstellar travel?

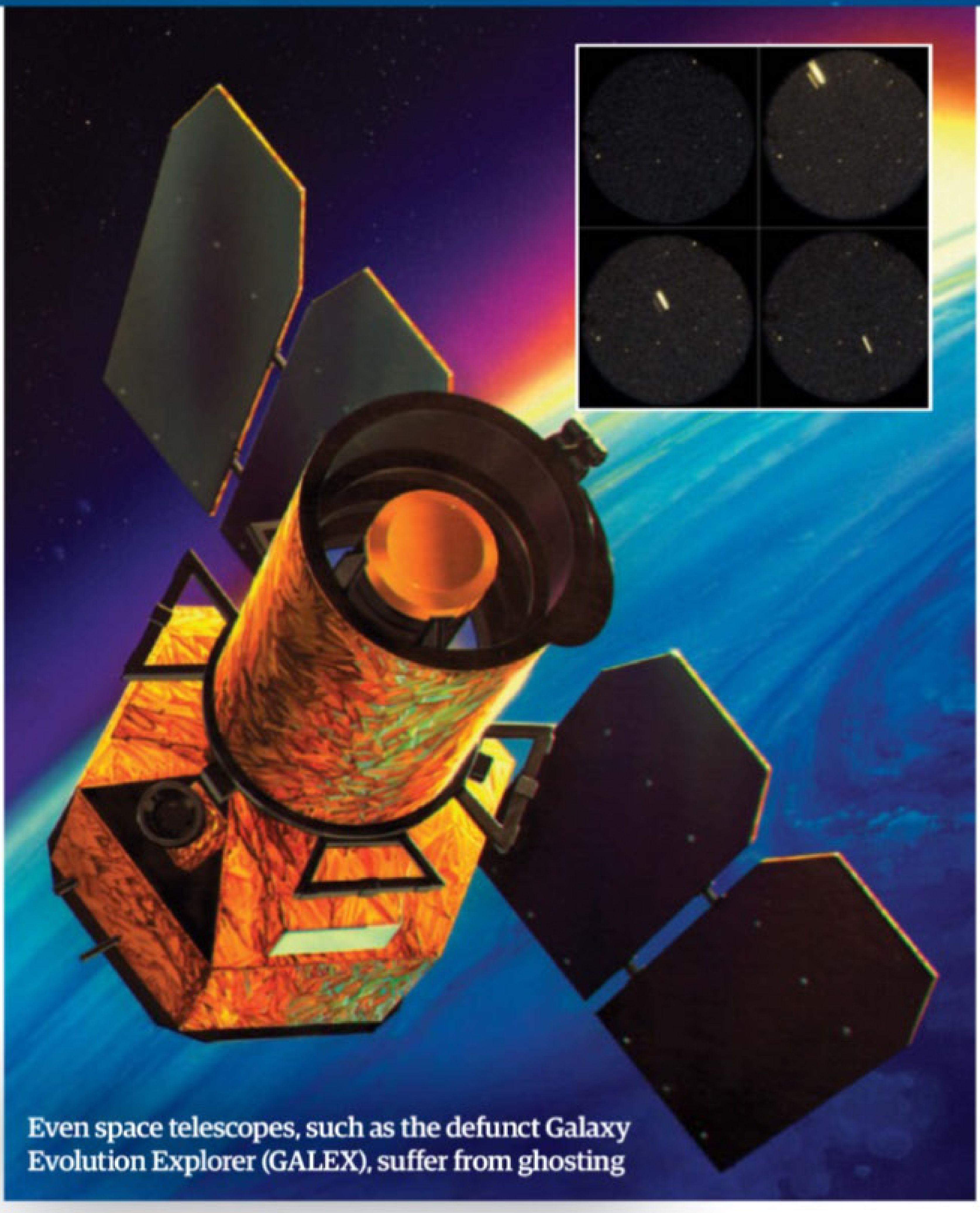
Hannah Hall

The short answer is yes, you very much would. The dangers of interstellar travel would be the same as those of Solar System exploration, with the added danger of communication lag with the Earth being massive.

Interstellar space is as much of a vacuum, if not more so, than the space in which our Solar System orbits. Because you would be further from the Sun, the hazards of bright sunlight, solar radiation and temperature would be reduced.

Straying from your pressurised spacecraft would lead to experiencing the simultaneous expansion of gases trapped within your body, suffocation due to lack of oxygen, freezing due to the extreme cold and boiling of your bodily fluids. **SA**

With so many hazards involved in interstellar travel, you would definitely require a spacesuit



Even space telescopes, such as the defunct Galaxy Evolution Explorer (GALEX), suffer from ghosting

ASTRONOMY

What does ghosting mean?

Kevin Bates

Ghost images, also known as ghosting, can occur in binoculars and telescopes when looking at night-sky targets. When an astronomer complains about ghosting after a night of observing, they have seen double of their target.

What's happening here is that internal reflections, sometimes called scatter, have caused light passing through an eyepiece, for instance, to disperse. What's left is a reduction in the contrast of an image. To get around this problem, eyepieces with the appropriate ratio of air-to-glass are preferred to keep ghosting to a minimum.

Thin film coatings over lens surfaces also assist with the scatter that can lead to ghosting. They work by reducing reflections and scattering by changing the refraction of light passing through the lens. **GL**

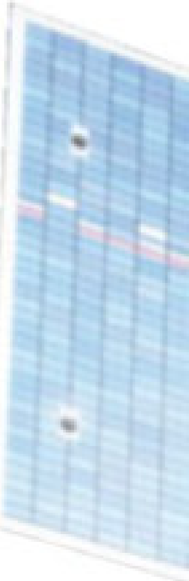
DEEP SPACE

How are pulsars used to identify our position in space?

Shaun Williams

Pulsars could effectively act as the GPS satellites of deep-space exploration due to the ease with which they can be located and identified. As a type of neutron star – the dense remains of a star that has reached the end of its life – they emit pulses of radiation with a very regular period and directionality, making them easy to identify.

This means a deep-space vessel could use the location of the Sun, along with at least three pulsars to triangulate its position in the cosmos. While the Sun is technically not stationary in space, this can be corrected by enabling pulsars to guide spacecraft in the same way GPS guides our cars. **SA**



Pulsars, like that of the crab nebula, could act as GPS satellites for deep-space exploration

DEEP SPACE

What level of oxygen is indicative of life on an exoplanet?

Stuart Rowe

Biological processes are thought to be a major contributing factor to the levels of atmospheric oxygen on Earth. We therefore often think of oxygen as a biosignature – a chemical marker in the atmosphere that's closely associated with the presence of life.

Oxygen is highly reactive, so a large amount of the element in an exoplanet's atmosphere suggests that there's likely a significant oxygen producing process that's ongoing. Although this could be attributed to life, there are a number of abiotic processes that can produce oxygen.

As such, studying oxygen levels alone is unlikely to be enough unless combined with other gases. Scientists think that finding high levels of both oxygen and another biosignature, such as methane, may be a much better indicator. **ZB**

Oxygen signatures are thought to be strongly indicative of life on other planets

SPACE EXPLORATION

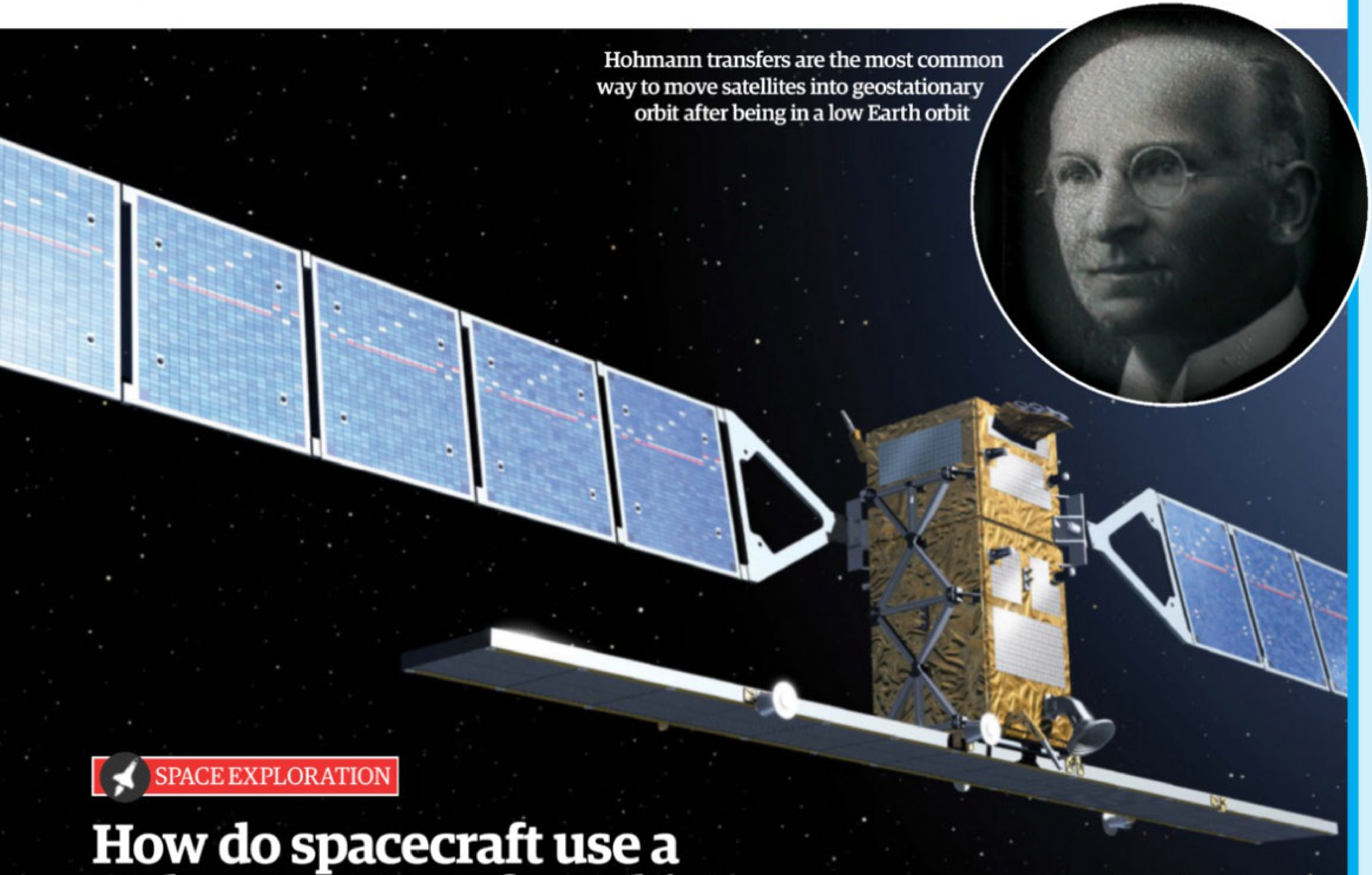
How do spacecraft use a Hohmann Transfer Orbit?

Charlotte Kane

Space probes manoeuvre from one circular orbit to another using a Hohmann Transfer Orbit (HTO), devised by the German astronomer Walter Hohmann.

Imagine launching the next probe to Mars. Blasting off from Cape Canaveral, it enters a circular orbit around Earth. Firing its engines at the right time, the spacecraft is propelled onto an HTO, which is an elliptical orbit around the Sun that takes the probe to Mars.

One of the tips of the elliptical orbit is located where the probe left Earth orbit, while the other needs to clip Martian orbit at exactly the same time the planet arrives there. With an engine burn, the probe enters into a circular orbit around the Red Planet. Satellites can also use HTOs to lift themselves from low Earth orbit to a higher orbit. **GL**



Hohmann transfers are the most common way to move satellites into geostationary orbit after being in a low Earth orbit

Quick-fire questions

@spaceanswers

What's the difference between the Local Group and Virgo supercluster?

The Local Group, which our galaxy is part of, is in turn a part of the Virgo supercluster along with over 100 other galaxy groups and clusters.

What exactly are nebulas made of?

Nebulas are interstellar clouds made up of dust, hydrogen and helium gas, as well as plasma.

What was the first satellite sent into space?

The Soviet Union's Sputnik 1 was the first artificial satellite sent into space. It was launched into an elliptical low Earth orbit in October 1957.

What colour is the far side of the Moon?

Using measurements made by the sensitive camera at the Mauna Loa Observatory in Hawaii, astronomers have found that the far side of our lunar companion is turquoise – due to light reflected by the Earth.

Which planet becomes the brightest when seen in the night sky?

The second planet from the Sun, Venus, is the brightest planet in the night sky. It can reach an apparent magnitude of -4.9 thanks to its reflective atmosphere of sulphuric acid clouds.

What is the Sloan Great Wall and how big is it?

This is a great cosmic structure formed by a giant wall of galaxies. The Sloan Great Wall measures around 1.38 billion light years in length. This makes it one of the largest celestial structures in the known universe.

What is a syzygy?

This is where three or more astronomical bodies, in a gravitationally bound system, are roughly aligned in a straight line.

Quick-fire questions

@spaceanswers

What is meant by the Dog Days of Summer?
It's the period of summer in the Northern Hemisphere when the Dog star, also known as Sirius, is hidden from view by our Sun's bright glow.

Can plants survive on a planet around a red dwarf star?
A planet that orbits a red dwarf would have a sky permanently shaded a bloody crimson. This red light would affect any vegetation and cause them to be black in colour, rather than greens or other colours we usually expect plant life to be.

What does the term prograde mean?
This is the usual forward and eastward movement of a planet through the constellations that make up the zodiac.

What is a bolide?
A bolide is a very bright meteor that either fragments or explodes. If the observer is close enough to the meteor, then they will be able to hear the explosion.

What is microgravity?
This is when things seem to be weightless and when the pull of gravity is not very strong. In these conditions it's easy to move heavy objects - you would be able to move things that weigh hundreds of pounds with just the tips of your fingers.

What happened to the Space Infrared Telescope Facility?
The SIRTF was the former name of the Spitzer Space Telescope. It was launched in 2003 and is still currently studying the universe.

What colour is the Sun?
Despite being known as a yellow dwarf, our Sun is in fact white.

The James Webb Space Telescope will have an 18-piece mirror that will fold out when it reaches space

SPACE EXPLORATION

How can we fold out structures in space without them breaking?

Brian Timms

We can move and fold out large structures because in space there is very little resistance. On Earth when we want to move or articulate large structures, we must work against several forces. In space we only have to contend with mechanical friction.

In a microgravity environment, such as in orbit around Earth, objects are effectively weightless. This means we don't have the mechanical strain of moving a large object in opposition to gravity. A great example of this was the doors on the Space Shuttle cargo bay. The motors powering these doors were not powerful enough to open them down here on Earth, but they were more than adequate to do so in the microgravity of low Earth orbit. **JB**

Abell 520, also known as the Train Wreck cluster, shows dark matter in this composite image

DEEP SPACE

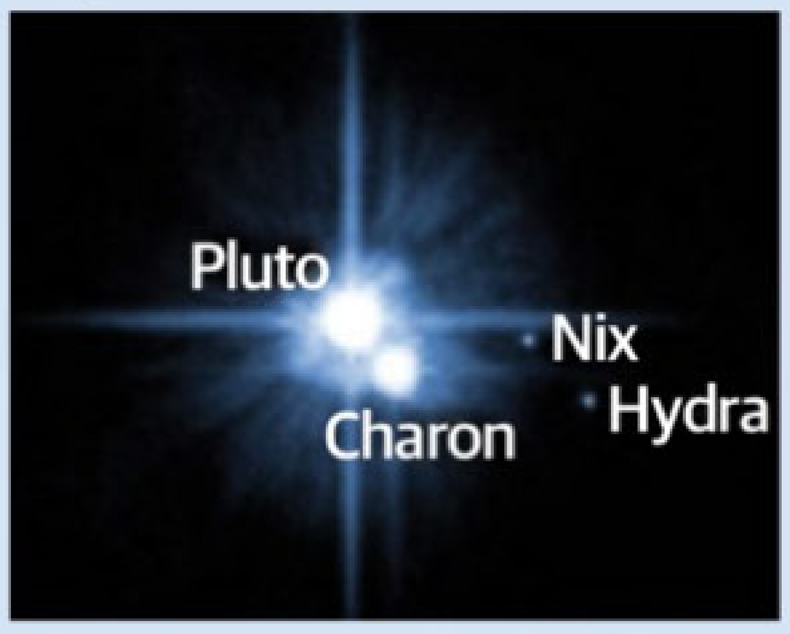
Are there any rival theories to dark matter?

Lewis Brown

There is a rival theory to dark matter and that's MoND (Modified Newtonian Dynamics). As its name implies, MoND proposes that Newton's law of gravity must be changed in order to explain the missing mass in our universe.

Proposed by Mordehai Milgrom in 1983, MoND only works when the gravity of an object is large. Yet, and even by Milgrom's admission, MoND may not hold when gravitational accelerations are small. In comparison, dark matter seems to account for the missing matter in the universe without having to modify any laws of physics at all.

Despite this, however, some scientists support MoND. Even Vera Rubin, who found the first direct evidence for dark matter, leans towards this idea. **GL**



Charon is just more than half the size of dwarf planet, Pluto

ASTRONOMY

Why is Charon almost exactly the same size as Pluto?

William Cartwright

In short, we don't currently know exactly why Charon is more than half the size of the dwarf planet Pluto, even though it is technically the latter's moon.

Of all the planet-moon systems in our Solar System the one that most resembles that of Charon and Pluto is actually our own - the Earth and the Moon. The Moon is roughly a quarter of the size of the Earth. It's therefore possible that they may well both have had a similar formation process: a collision with another large celestial body. The collision may have resulted in a large portion of the parent body to have separated off, but then captured as a moon. **ZB**

Questions to... @spaceanswers /AllAboutSpaceMagazine questions@spaceanswers.com

A combination of water vapour and dust particles form noctilucent clouds

ASTRONOMY

How do noctilucent clouds form?

Fern Berger

Noctilucent clouds (NLCs) tend to look like delicate streaky clouds, which can only be seen in the twilight hours between May and August. They are the highest clouds we know of at around 80 kilometres (50 miles) up in the mesosphere layer of our atmosphere.

Water vapour and dust particles are needed for an NLC to form, but both are fairly sparse at that high altitude.

It's thought that a supply of dust may come from micrometeors or from volcanic eruptions, while water vapour may have been lifted up through the lower atmospheric layers or created by chemical reactions. Together these two components form tiny ice crystals, which are the primary components of an NLC. Cold levels are needed for ice crystals to form and at a chilly -123 degrees Celsius (-184 Fahrenheit). **ZB**

The MRO is capable of detecting Beagle 2, but we're still yet to find it

SPACE EXPLORATION

Can the MRO orbiter image the crashed Beagle 2 lander?

Harriet Lane

In order to truly put this to the test, we would have to find where the Beagle 2 lander crashed in the first place! Just where the European craft smashed into the Martian surface in late 2003 is still a mystery and scientists are still scratching their heads as to what exactly went wrong.

The Mars Reconnaissance Orbiter (MRO) carries a powerful camera known as HiRISE, which has been regularly taking high-resolution images of the Isidis basis region – where Beagle 2 was supposed to have touched down. Provided there are no dust storms raging on Mars' surface and Beagle 2 isn't completely buried in dust, the MRO should eventually come across the lost lander. It's just a case of continuing to scan Mars' surface until it's found. **GL**

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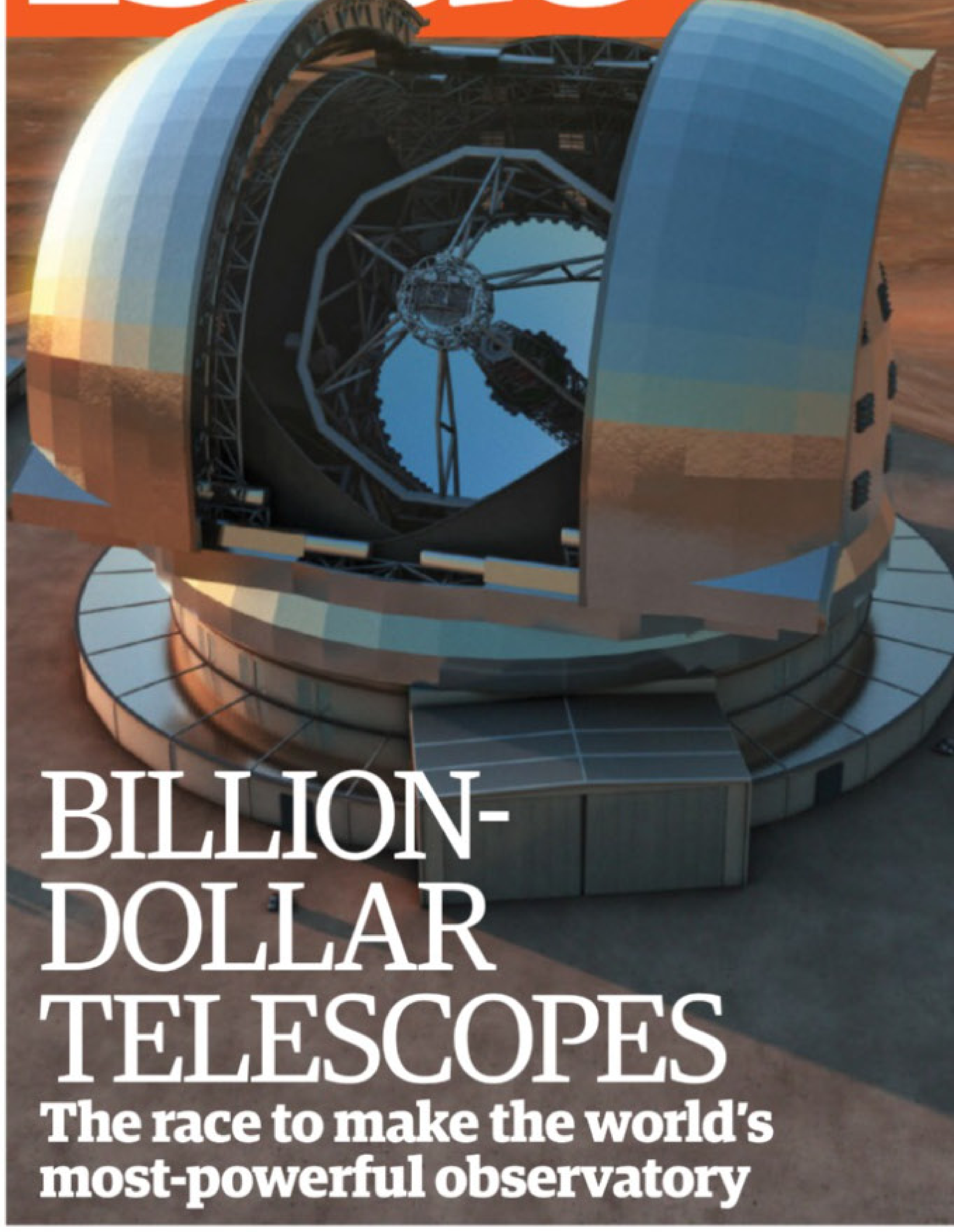
Next Issue



BILLION-DOLLAR TELESCOPES

The race to make the world's most-powerful observatory

MYSTERY OF THE GIGANTIC STAR

Discover the supermassive stellar object that science can't explain

10 COLOSSAL COSMIC COLLISIONS

Jaw-dropping space impacts that shook the foundations of physics

20 MAJOR SPACE DISCOVERIES

How yesterday's science has forged our future in space

In orbit
24 Jul
2014

DARK LUNAR POLE
METEOR SHOWER VIEWING
PLANETARY PROTECTION
SPOTTING SCOPE STARGAZING
SPIDERFAB SPACE CONSTRUCTION
MILKY WAY MAGNETIC FINGERPRINT

STARGAZER

GUIDES AND ADVICE TO GET STARTED IN AMATEUR ASTRONOMY

In this issue...

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88 **What's in the sky?** Find the most-spectacular nighttime objects

90 **Me and my telescope** Readers showcase their best astrophotography images

96 **Astronomy kit reviews** The latest essential astronomy gear and telescopes reviewed

Guide to solar observing

Forget late and cloudy nights, our Sun provides the perfect target for daytime astronomers

It's summer, the nights are shorter and the days are longer. It feels like there aren't enough hours in the evening to do enough astronomy before dawn. This is where daytime astronomy comes in, to see you through the lighter months with the celestial object that takes centre stage in the sky - the Sun.

Being so close to us, the Sun can often be overlooked. However, its proximity tells us much about other stars - particularly those in the main sequence - that are too far away for us to able to get detailed observations. In fact, when you're looking at the Sun, it's exactly the same as observing any other G-type star up close.

While being so near to the star has its pluses, it also has a downside. Our Sun is much brighter and hotter than any of those stars in the sky because of its proximity, meaning that every care must be taken in observing it.

The Sun is a potentially dangerous viewing object - its luminosity and an observer's carelessness is a very bad combination for the unprotected eye. You should never look at the Sun directly - either with the unaided eye or using an unfiltered telescope - you will almost certainly cause permanent damage to your eyesight. That's not to say you're unable to look through a telescope at the Sun, however, you just need to ensure that you have the correct tools to do so.

If you own a refractor, then try out the projection method. Provided it's done properly, this is one safe way of observing the Sun cheaply and effectively. Here we've put together a step-by-step guide on how to transform your instrument.

If you prefer to look at the Sun directly, then you can purchase filters that block out the infrared heat, 99.9 per cent of sunlight and the ultraviolet radiation that you don't want to reach your eyes. What you get is a greatly dimmed image where features such as sunspots and solar prominences become much more obvious.

Depending on the type of filter you end up purchasing, you must ensure it isn't damaged in any way. You have the choice of a purple calcium-K filter to see magnetic storms, or a hydrogen-alpha (H-alpha) filter to check out solar prominences, or a solar white-light filter to study sunspots.

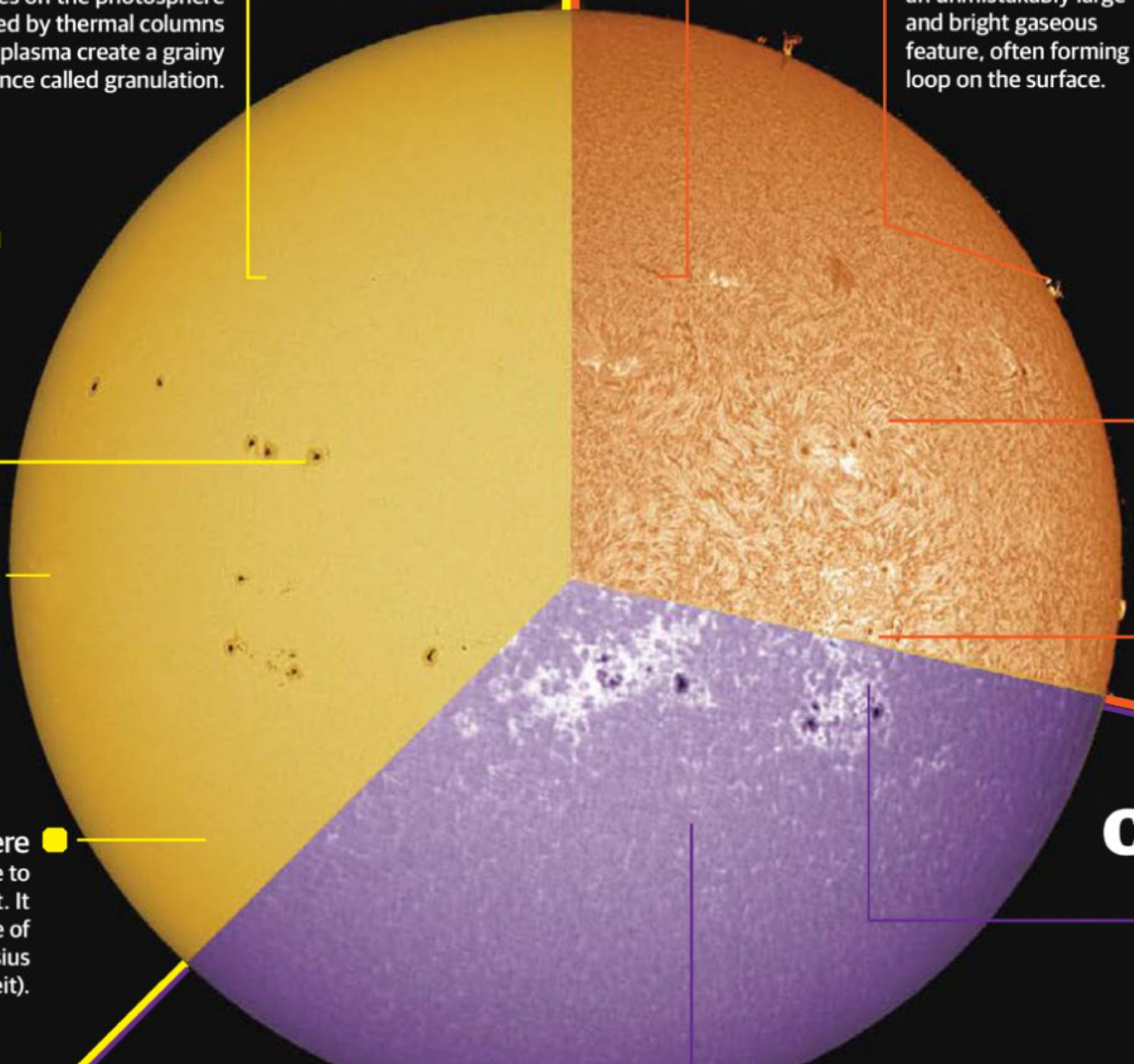
These should fit snugly and crucially you should obtain them from a reputable dealer. While filters as well as dedicated solar telescopes are very costly, they're certainly worth every penny as the dynamic solar surface is truly revealed.

Safety first

Warning! If you are attempting to view the Sun, you need to be careful, especially if using a telescope or other optical aid. Unless properly filtered, even a glimpse of the Sun through any optics including a camera lens, can permanently damage your eyesight.

The Sun uncovered

With a choice of filters, you can observe a variety of fascinating solar features



White light

Solar granulation
Granules on the photosphere caused by thermal columns of plasma create a grainy appearance called granulation.

Sunspots
Sunspots are temporary and usually appear in pairs. They are between 2,700 and 4,200 degrees Celsius (4,892 and 7,592 Fahrenheit).

Limb-darkening
This is a noticeable darkening to the Sun's gaseous limb due to a drop in density and temperature.

Photosphere
The surface is visible due to its emission in white light. It sizzles at a temperature of around 5,000 degrees Celsius (9,000 degrees Fahrenheit).

Hydrogen-alpha

Filament
These are relatively cool and dense loops of gas suspended above the surface of the Sun.

Prominence
A solar prominence is an unmistakably large and bright gaseous feature, often forming a loop on the surface.

Chromosphere
Above the photosphere, this is the second layer of the Sun. Due to its low density and the overwhelming brightness of the photosphere, strong filters are required to see it properly.

Plage
Usually found around sunspots, these bright regions can be found in the chromosphere and close to the faculae in the photosphere below.

Calcium-K

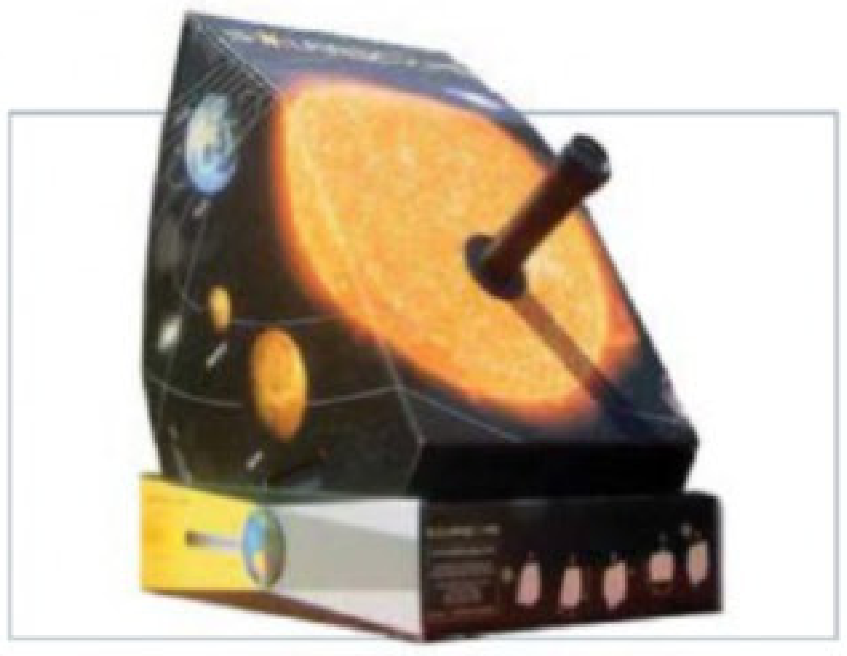
Active region
Appearing very bright, this is a region of high magnetic fields. Sunspots, solar flares and coronal mass ejections can be found here.

Chromospheric network
Formed by magnetic field lines, the chromospheric network consists of long thin webs of brightness

Solar safety toolbox

Solar filters
Filters often made of aluminium sheeting or glass enable you to observe the Sun's features safely by blocking out harmful light.

Solar telescope
Solar telescopes are made in such a way that they show a specific wavelength of light. They reveal more prominences and active regions.



Sun projector
These feature a small telescope and mirror that projects the Sun's image. A cardboard Sun projector could be used in place of a telescope.

Herschel prism
These are used for safe solar observation, where most of the light from the Sun is refracted. They cannot be used with reflector telescopes.

View the Sun in white light

From sunspots to granulation, there's plenty to see in natural light

When we view the Sun in white light, we're seeing it as naturally as if we were able to look at it with the naked eye. The surface of the Sun that's visible to us from Earth is called the photosphere and while it looks rather plain to the eye, you'd be surprised to discover what you can actually see with the help of a telescope and white-light filter. In fact, viewing the Sun in this waveband as well as imaging it is the easiest and cheapest way to get into solar astronomy.

What you'll be able to see depends on the conditions, the Sun's activity at the time and the equipment you have. A telescope of at least four inches or above will show you what is known as granulation, which is caused by the convection of material from the Sun's interior to the surface and gives the Sun a sandy-looking texture. While the Sun is massive, these granules are typically 1,500 kilometres (932 miles) wide, so under poor seeing conditions you're likely to witness very coarse mottling across large areas of the Sun's surface. They are extremely short-lived, with individual granules only lasting 20 minutes or so.

The Sun is ever-changing, so more features will constantly pop into view, such as limb-darkening and bright patches known as faculae, as soon as you put your eye to a filtered telescope. While stunning in their own right, the active Sun also offers up another feature that excite astronomers – sunspots.

Sunspots appear when the Sun is active and are often clustered in groups. If you look close enough, you'll find a typical sunspot has a dark, cooler region (umbra) surrounded by a lighter region (penumbra).

> "The Sun is ever-changing, so more features will constantly pop into view"

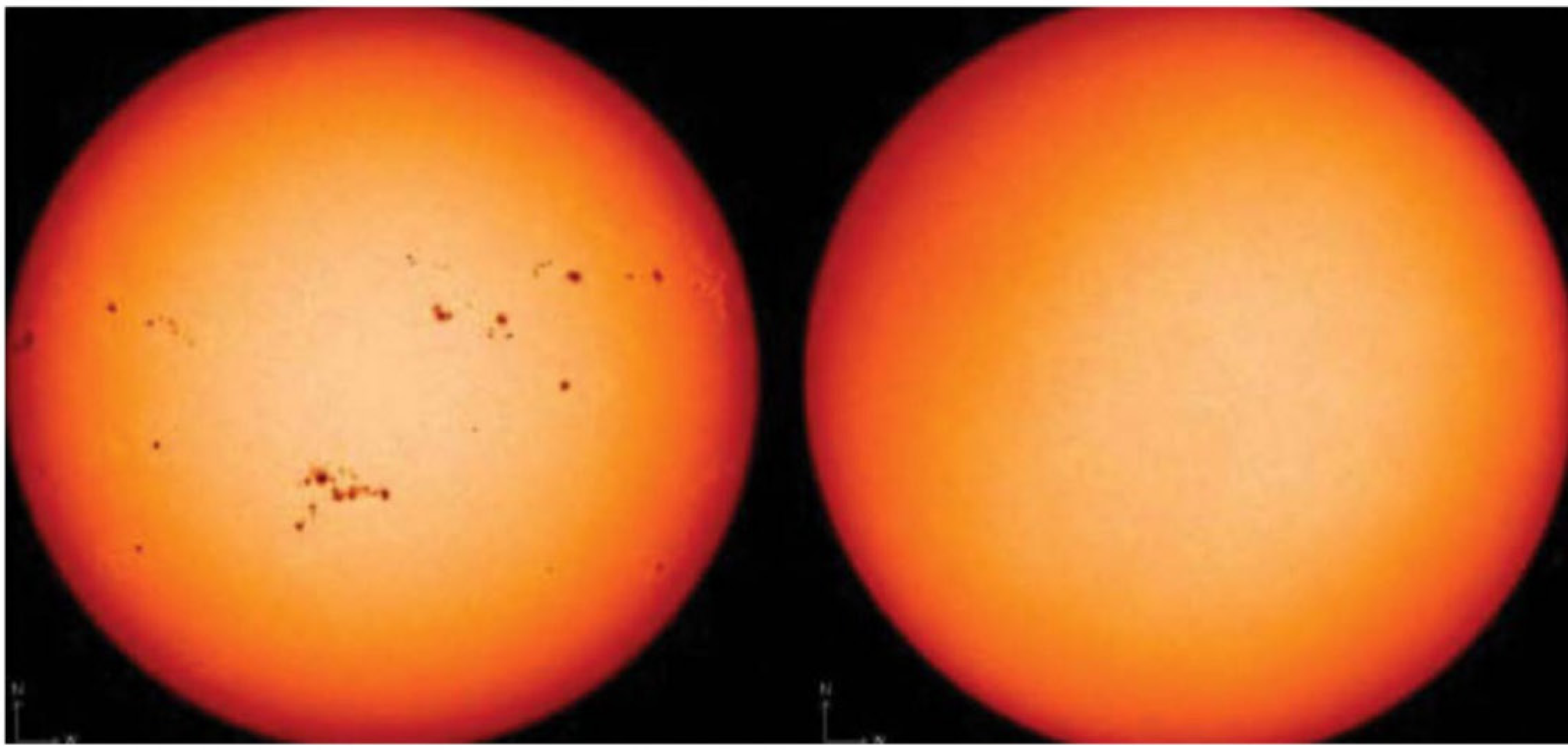
Glass vs film

There are a couple of types of white-light filters available for amateurs to fit onto their telescopes, but which one you decide to purchase depends very much on your budget.

Mylar are the cheapest white-light filters, they cost anywhere from £40 ($70) upwards, while glass filters start at around £70 ($120). These will provide you with a more-natural orange-yellow look to the Sun's disc, while the cheaper alternative will give a blue tinge.

Following the solar cycle

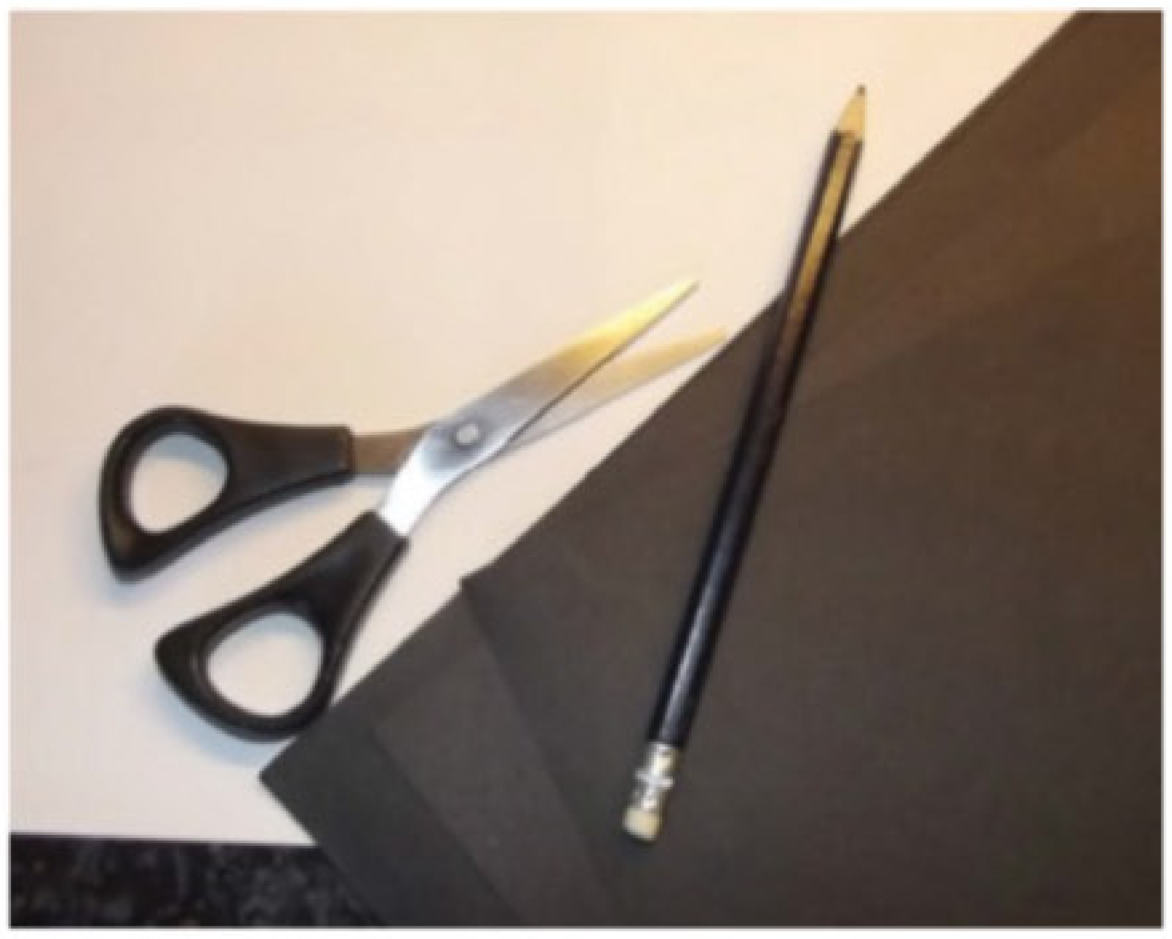
When the Sun is highly active, sungazers will be able to see more sunspots and more detail on the photosphere. However, while the Sun is fierce, it isn't always massively active. Its activity varies over an 11-year cycle, with activity rising and falling through the solar maximum and minimum. The Sun can appear featureless at minimum, but the years surrounding solar maximum are the most exciting, with plenty of sunspots for astronomers to observe. Associations such as the NOAA's Space Weather Prediction Centre will give you an idea of the most active periods.



Use your telescope to observe the Sun

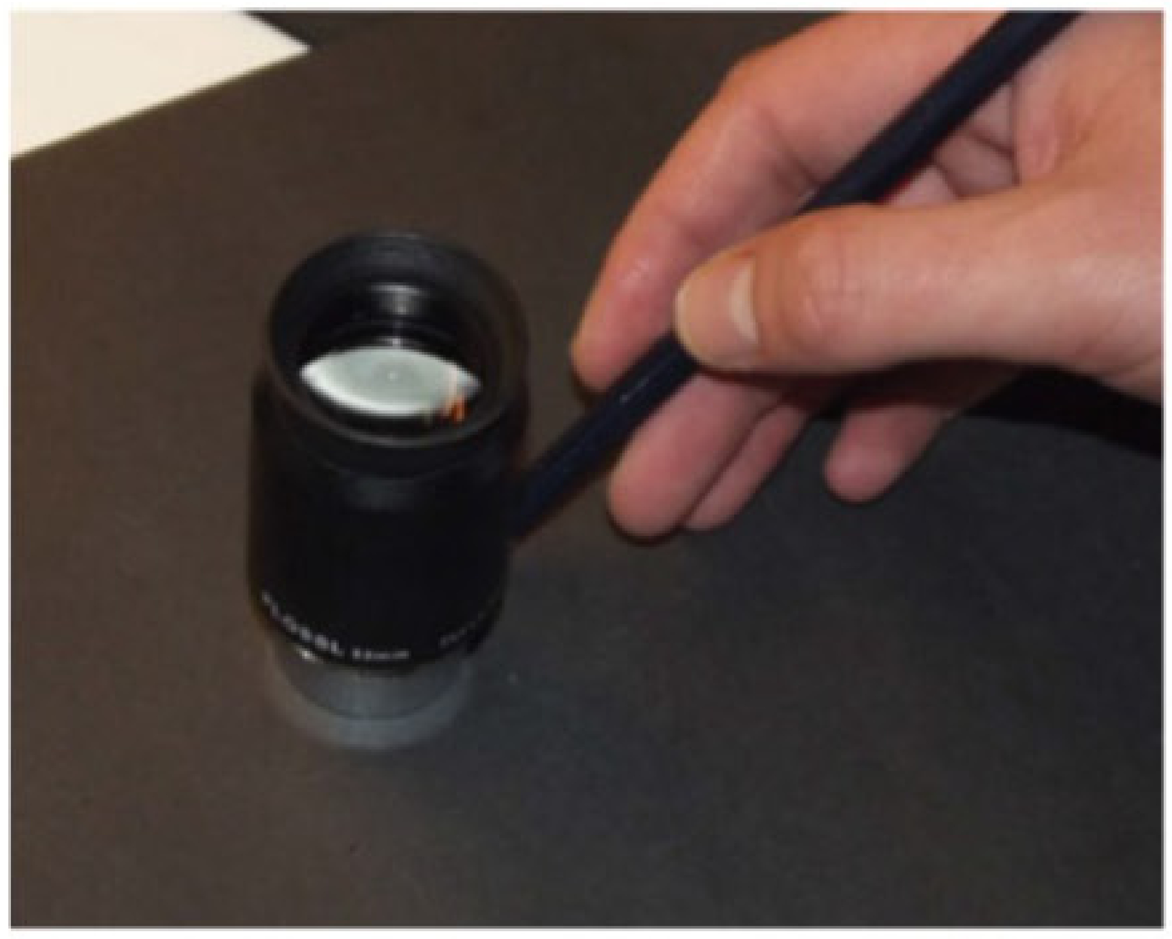
We show you how to safely view our nearest star without a solar telescope

It's no secret that solar telescopes and filters that can be fitted to standard devices are expensive. These instruments are specialised and don't offer the versatility that standard night-sky telescopes do. Unless you are a passionate solar observer, or a seasoned astronomer with an interest in solar observing, then this is a luxury that many can't afford. If you don't know anyone who has a solar telescope and you want to observe the Sun's surface, there's a simple, safe and very cheap way to do so.



1 Prepare the card

Find a piece of white card or poster board – ensure it's relatively thick, as this will be where the Sun's image will be projected.

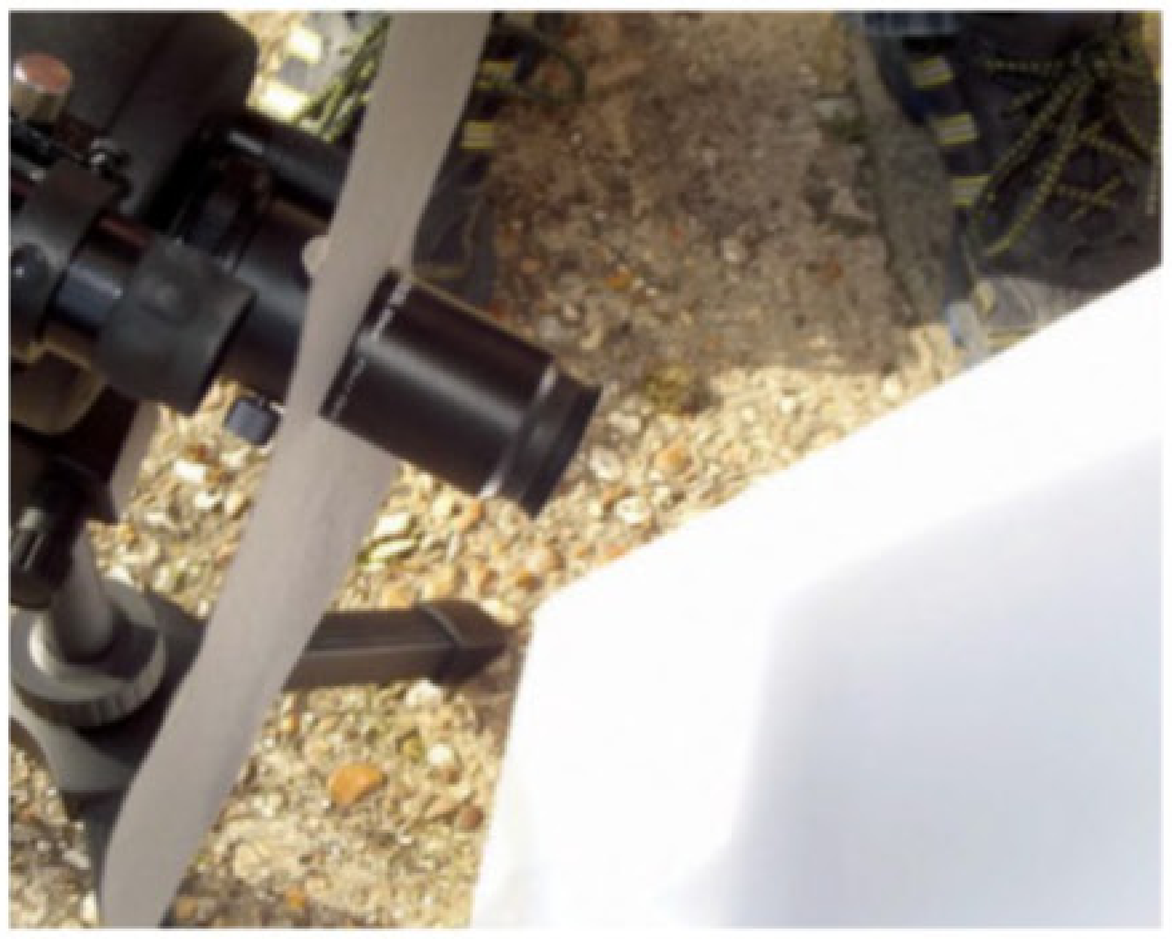


2 Cut around the eyepiece

You'll need to fit another piece of card around the eyepiece, removing your star diagonal and cutting a hole so that the card fits snugly.

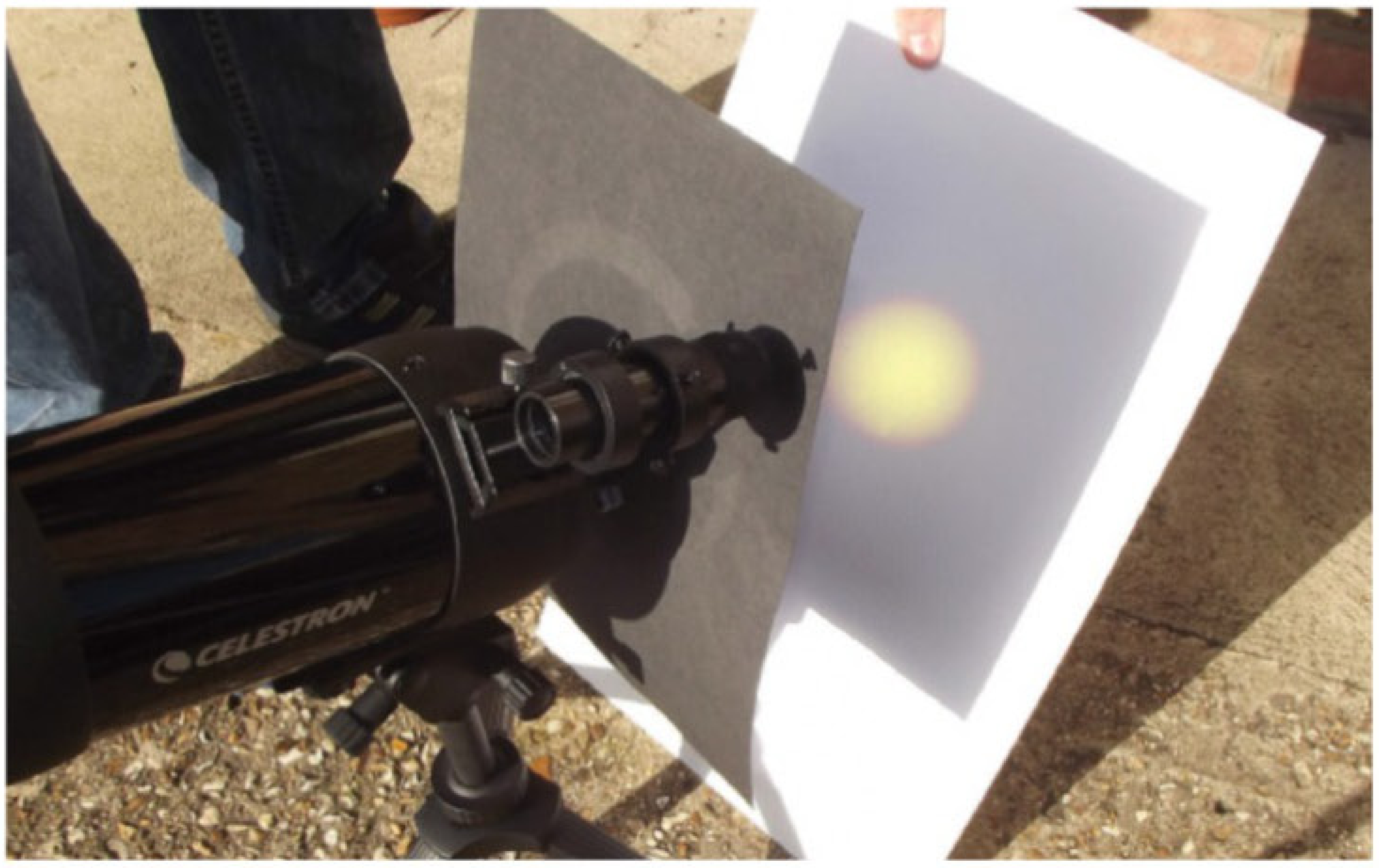
3 Keep your device cool

Choosing the right telescope is key, as the Sun is obviously hot. Make sure your device isn't overheating and that your finderscope is capped.



4 Line up your telescope

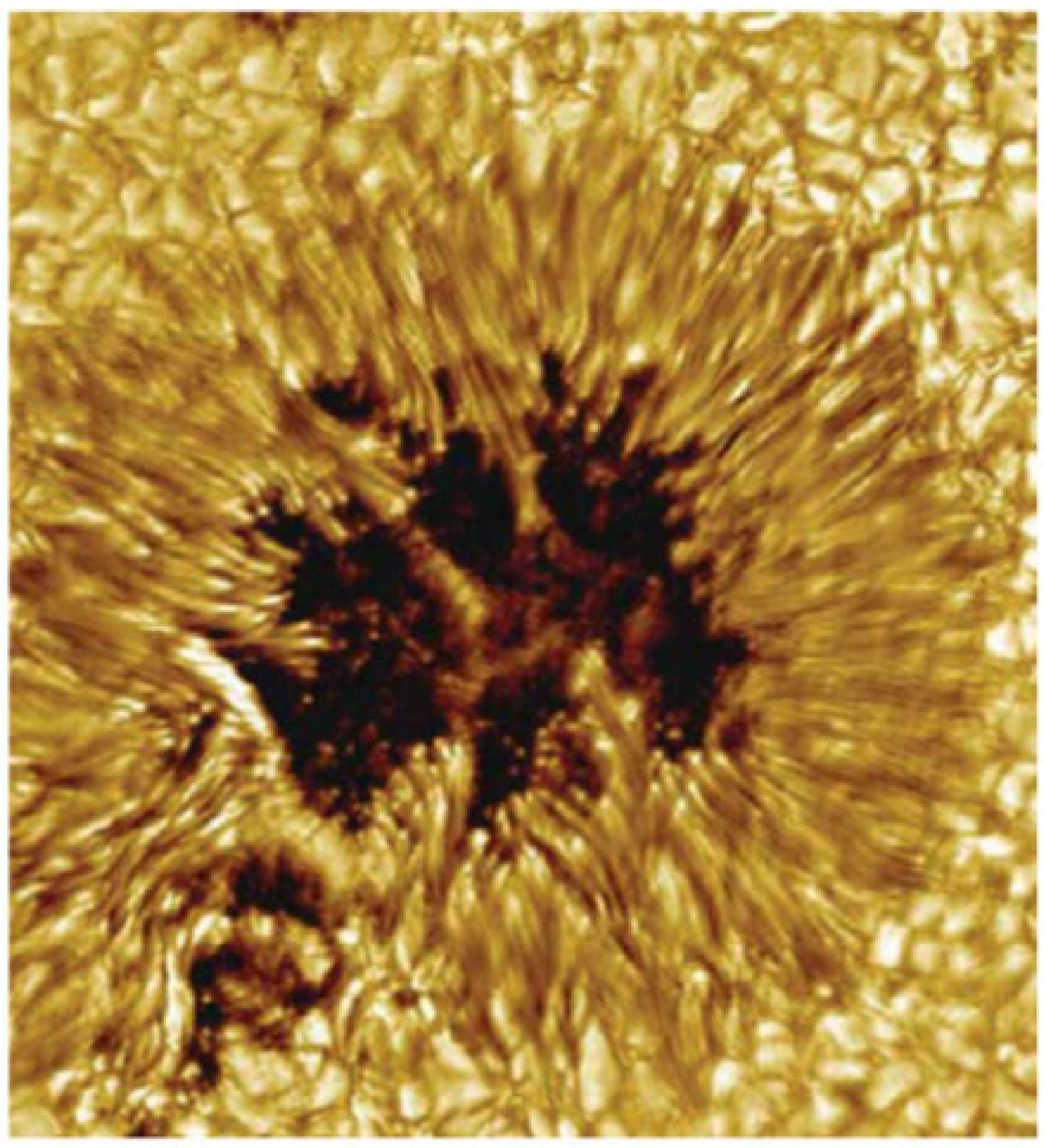
Take care when lining up your telescope and never look at the Sun. If you have trouble with this, buying a Sun-finder is your best bet.



5 View the projection

Using your white board as a reference, focus your telescope until you get a sharp view of the star. Since you'll be viewing the Sun through white light, you should be able to see sunspots, solar granulation and limb-darkening on the photosphere – also known as the visible surface.

A white-light filter shows us how the Sun would appear if we were to look directly at it safely



A typical sunspot has a cool region known as the umbra, surrounded by a lighter region dubbed the penumbra

Solar observer Stuart Hilliker shoots the Sun, picking out stunning detail in hydrogen-alpha

Find the chromosphere using hydrogen-alpha

Dimming the Sun's brightness reveals an abundance of solar activity

Bright and full of intensity, our Sun is so dazzling that it hides away some of its fascinating features. That's why hydrogen-alpha filters are important when it comes to seeking out what really happens on its angry and turbulent face.

Whether you're looking to purchase a H-alpha filter to put on your pre-existing instrument, or a dedicated H-alpha solar telescope, they both fade out the bright light under a blanket, enabling the top layer of hydrogen to shine. This is the chromosphere and you'll be amazed by the huge amount of detail you'll be able to see here. With filters, the narrower the bandwidth, the finer the detail. For instance, a bandwidth of 0.1 nanometres won't show as much detail as 0.05 nanometres.

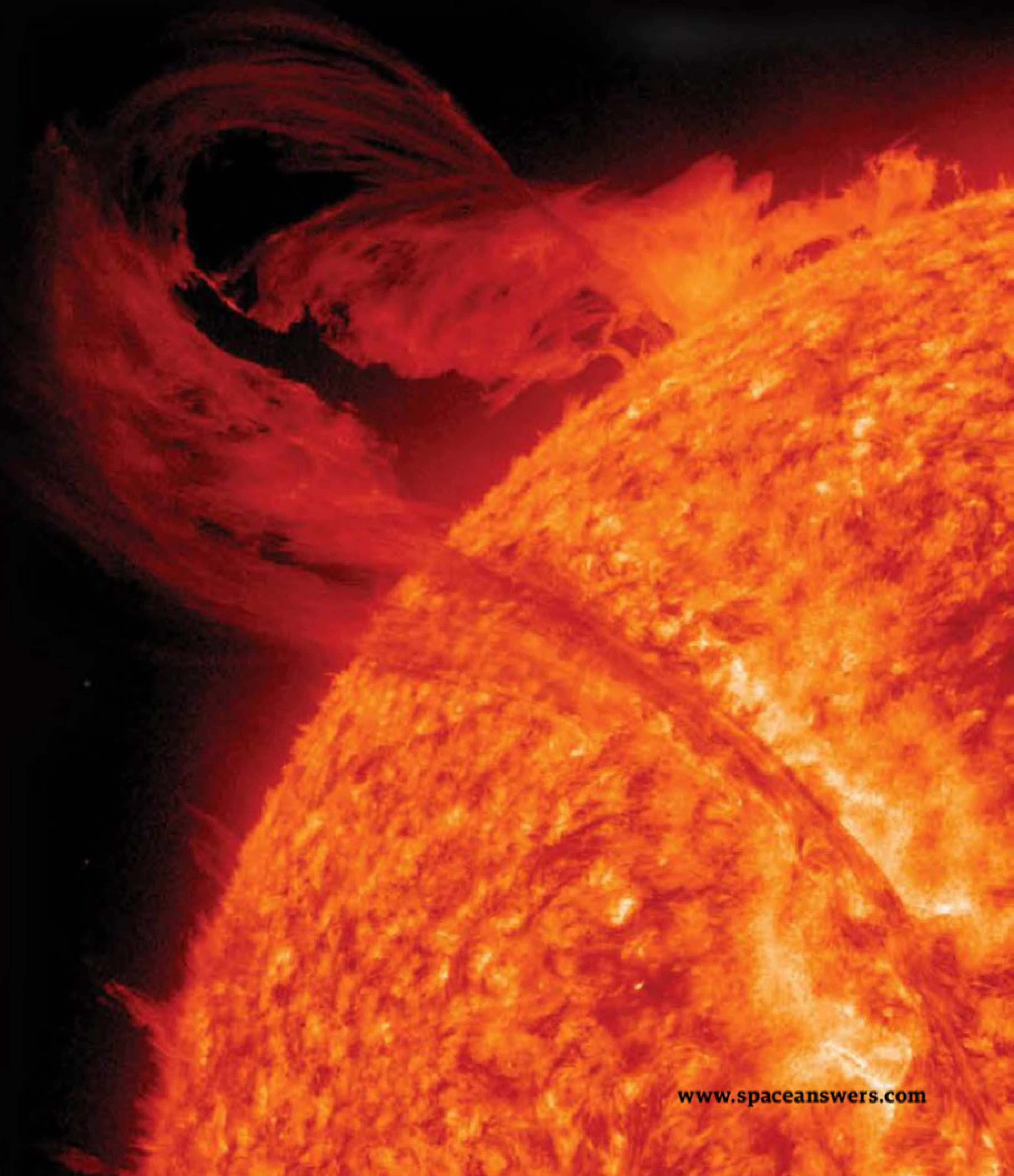
Through a hydrogen filter, the Sun will take on a warm orange colour, which has an almost rough, mottled appearance due to jets of hydrogen that erupt from the surface. Careful attention to areas of high activity, such as around sunspots, should reveal bright spots known as plage. Trace the limbs of the Sun and you could see solar prominences looping from it. When the same phenomena are viewed against the solar disc they are called filaments.

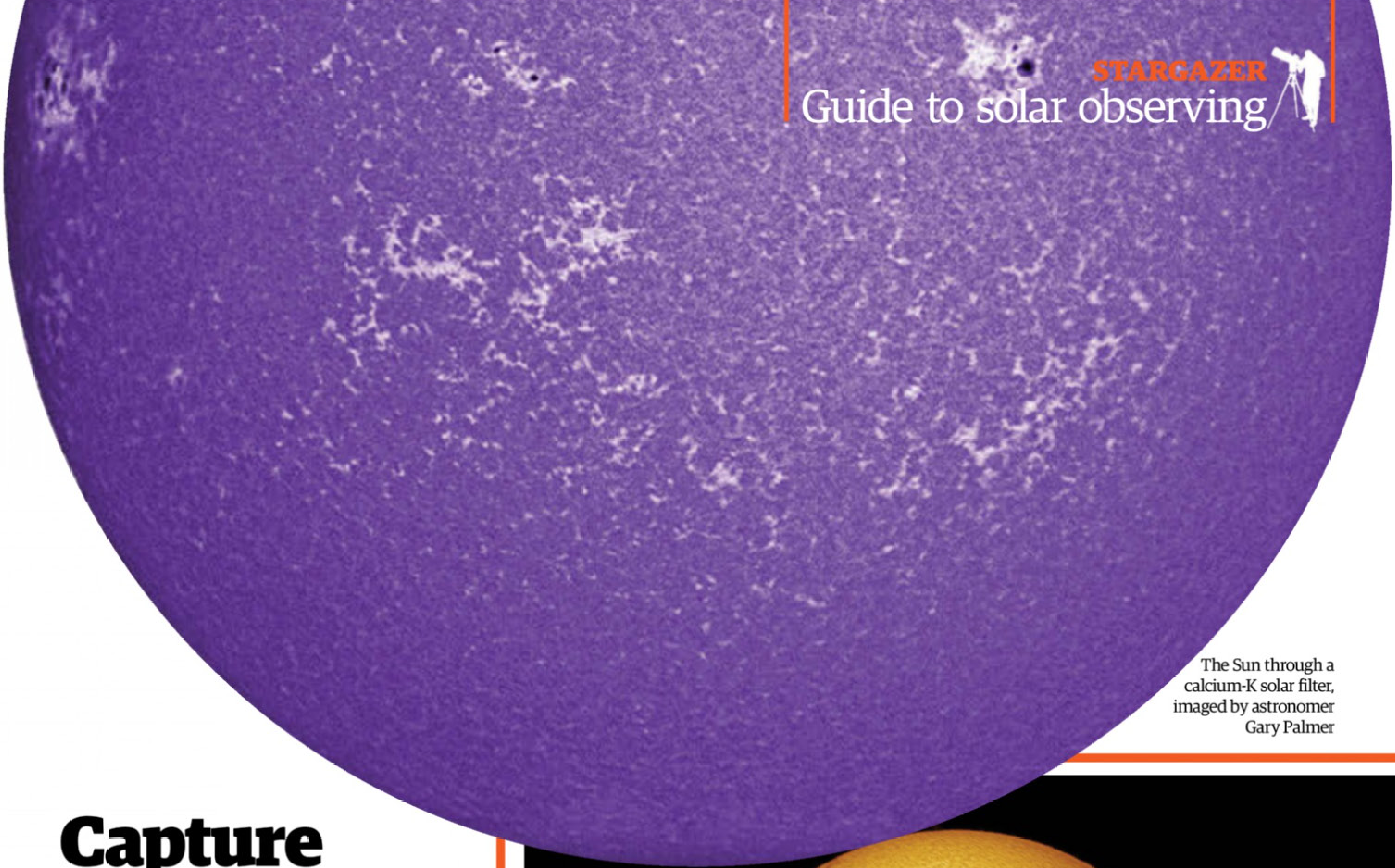
> "Trace the limbs of the Sun and you could see solar prominences"

Hydrogen-alpha filters reveal much more of our star's hidden layers

The solar telescope

Though they're expensive, solar telescopes are safe instruments for observing the Sun. If you have the funds and you're unsure about safely fitting a filter to a standard refractor telescope, then a safer bet would be to purchase one of these devices from a reputable dealer. Solar telescopes come with an optical device known as a Fabry-Pérot interferometer, which works to cancel out the harmful wavelengths that we don't want to reach our eyes.





The Sun through a calcium-K solar filter, imaged by astronomer Gary Palmer

Capture subtle details using calcium-K

Observe our star in purple to pick out the smallest features

Calcium-K filters and telescopes give the Sun's disc a characteristic purple colouration and, just like the hydrogen-alpha filter, show what's happening on the chromosphere. However, this time it's the lowest layer of the chromosphere being uncovered. You might think that, other than the obvious difference in shade, this filter shows pretty much the same as a white-light filter, but there is a difference. While subtle, you will see more detail in and around the most active regions of the Sun through this filter.

In calcium-K you won't be able to see any granulation, but you will see what looks like a network of lighter regions snaking their way across the Sun's disc. This is unimaginatively called the chromospheric network and the web-like pattern is brought about by bundles of magnetic field lines. Like hydrogen-alpha, you should also be able to see plage as bright patches surrounding sunspots (although these are perhaps best viewed in H-alpha). If you're lucky, you might also get to see prominences erupting the solar surface that, while not as bright through the calcium-K filter, can still be seen extending from the Sun's limb.

Imaging the Sun can present creatively stunning opportunities

Imaging our star

Taking shots of the Sun is a hugely rewarding experience. If you're new to solar imaging, you should obtain a white-light filter to begin with. A DSLR camera, high frame-rate camera, cooled CCD or webcam are also your best bet when it comes to solar imaging. Additionally, for the best results, it's important you acquire software that will assist with camera control, plus grading and stacking multi-frame movie files. You will also need to tweak your final image with a layer-based graphics editor, such as Adobe Photoshop.

© Alamy; NASA; NOAA

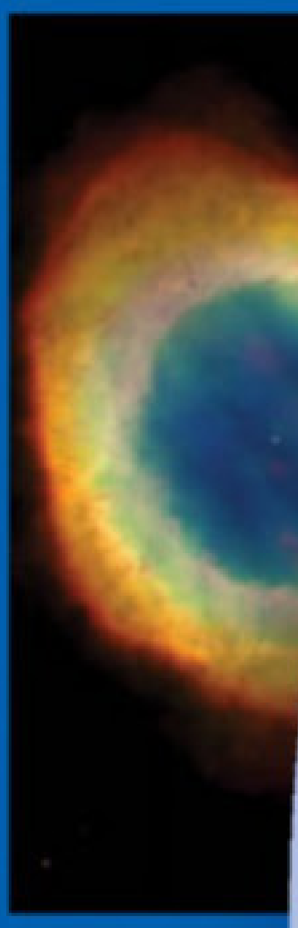
What's in the sky?

Darkness is fleeting in the Northern Hemisphere summer, but there's still plenty to see if you're prepared to stay up late

Planetary nebula M57

Viewable time: All through the hours of darkness.

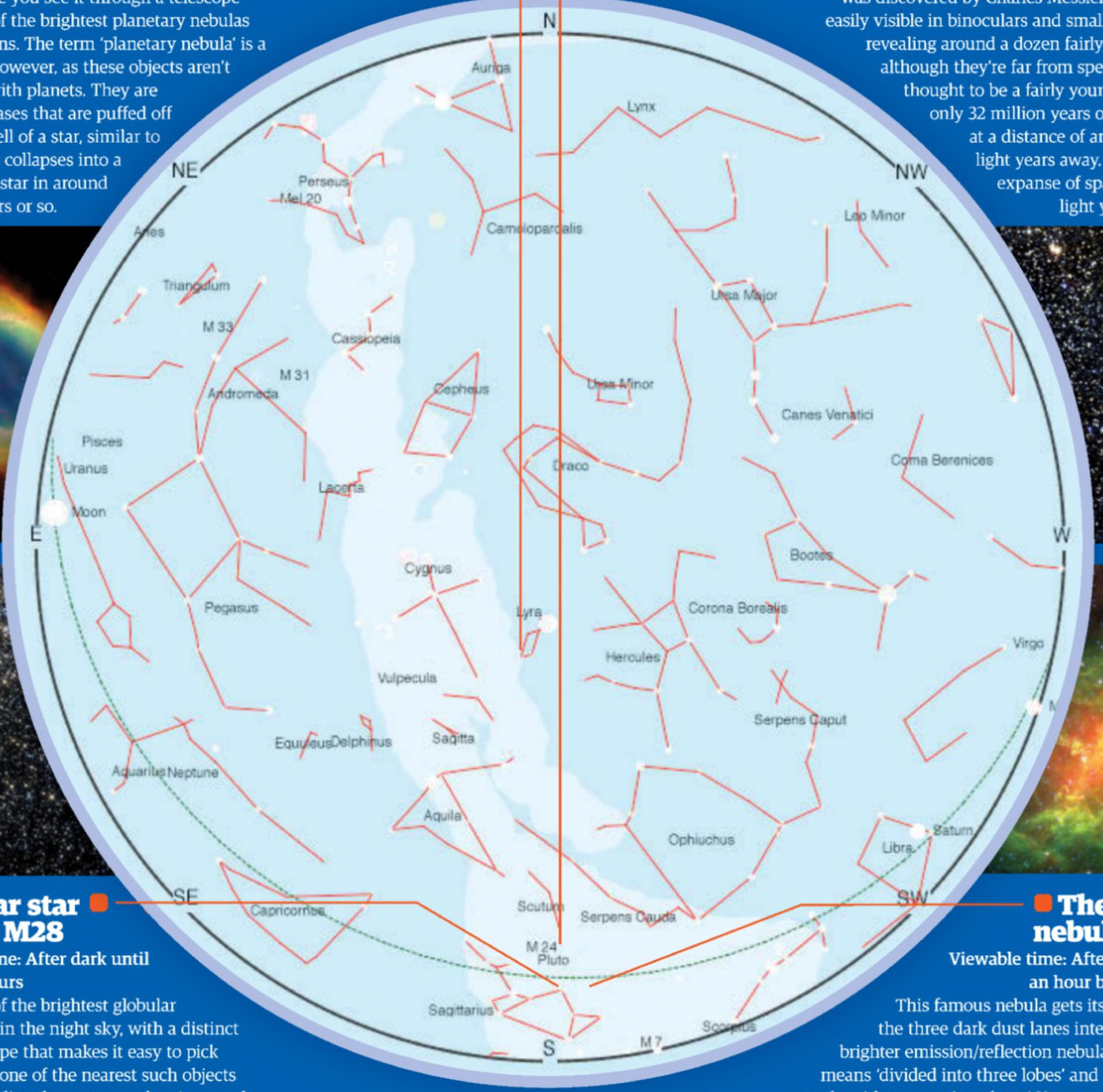
Also known as the Ring nebula, for obvious reasons, once you see it through a telescope M57 is one of the brightest planetary nebulas in the heavens. The term 'planetary nebula' is a misnomer, however, as these objects aren't associated with planets. They are bubbles of gases that are puffed off the outer shell of a star, similar to our Sun as it collapses into a white dwarf star in around 4 billion years or so.



Open star cluster M18

Viewable time: After dark until the early hours

This is an attractive open star cluster in the constellation of Sagittarius the Archer and was discovered by Charles Messier in 1764. It's easily visible in binoculars and small telescopes, revealing around a dozen fairly bright stars although they're far from spectacular. It's thought to be a fairly young cluster, at only 32 million years of age, and is at a distance of around 4,900 light years away. It covers an expanse of space about 17 light years across.



Northern Hemisphere

Globular star cluster M28

Viewable time: After dark until the early hours

This is one of the brightest globular star clusters in the night sky, with a distinct elliptical shape that makes it easy to pick out. It's also one of the nearest such objects to Earth and lies close to our galaxy's central bulge. At 12 billion years old it is also one of the oldest objects in the universe. It is about 60 light years across and is located around 18,000 light years away from us.

The Trifid nebula M20

Viewable time: After dark until an hour before dawn

This famous nebula gets its name from the three dark dust lanes intersecting the brighter emission/reflection nebula. The name means 'divided into three lobes' and has nothing to do with man-eating plants! You can pick it up as a hazy patch in binoculars, while a small telescope will show its structure. This stellar nursery is simply full of embryonic stars, all located at 5,200 light years away from Earth.

Open star cluster NGC 6124

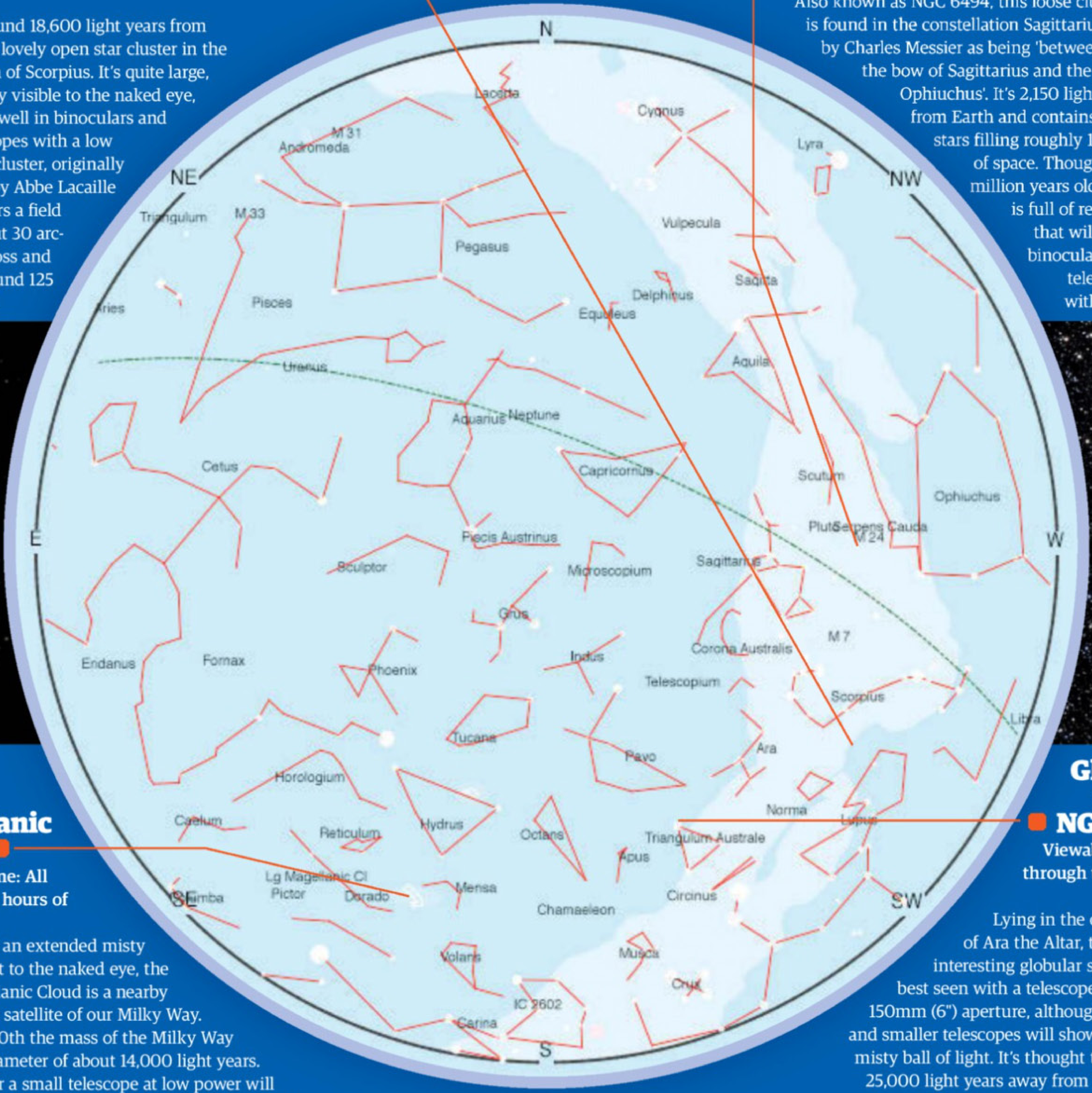
Viewable time: All through the hours of darkness

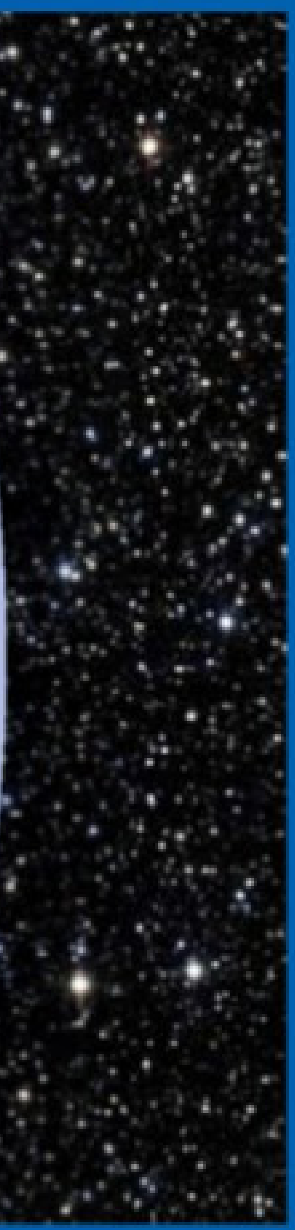
Situated around 18,600 light years from Earth is this lovely open star cluster in the constellation of Scorpius. It's quite large, but not easily visible to the naked eye, showing up well in binoculars and small telescopes with a low power. The cluster, originally discovered by Abbe Lacaille in 1751, covers a field of view about 30 arc-minutes across and displays around 125 visible stars.

Open star cluster M23

Viewable time: All through the hours of darkness

Also known as NGC 6494, this loose cluster of stars is found in the constellation Sagittarius, described by Charles Messier as being 'between the end of the bow of Sagittarius and the right foot of Ophiuchus'. It's 2,150 light years away from Earth and contains around 150 stars filling roughly 15 light years of space. Thought to be 300 million years old, the cluster is full of red giant stars that will show up in binoculars and small telescopes even with low power.





The Large Magellanic Cloud

Viewable time: All through the hours of darkness

Looking like an extended misty patch of light to the naked eye, the Large Magellanic Cloud is a nearby galaxy and a satellite of our Milky Way. It's only 1/100th the mass of the Milky Way and has a diameter of about 14,000 light years. Binoculars or a small telescope at low power will show its irregular shape and it's thought it was once a barred spiral galaxy, but has become irregular through tidal interactions with the Milky Way.

Globular cluster NGC 6362

Viewable time: All through the hours of darkness

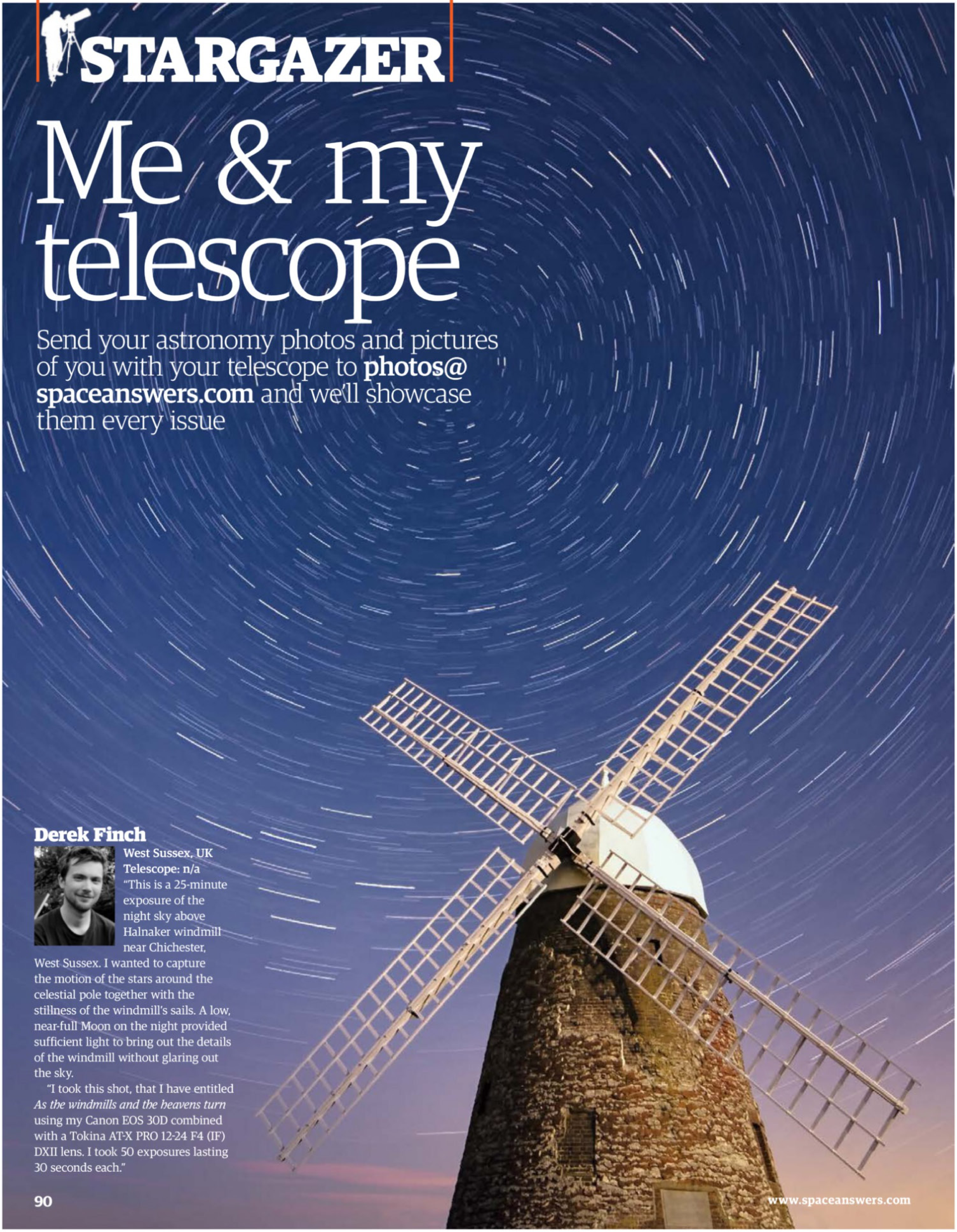
Lying in the constellation of Ara the Altar, this faint but interesting globular star cluster is best seen with a telescope of at least a 150mm (6") aperture, although binoculars and smaller telescopes will show it as a faint misty ball of light. It's thought to be around 25,000 light years away from Earth and at least 10 billion years old! Most of the stars that make up the cluster are old red giants discovered by James Dunlop in 1826.

Southern Hemisphere

©NASA; Hubble; Roberto Mura; ESO/ S.Brunier; JPL-Caltech; AURA; STScI; 2MASS; University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology

Me & my telescope

Send your astronomy photos and pictures of you with your telescope to **photos@spaceanswers.com** and we'll showcase them every issue



Derek Finch

West Sussex, UK
Telescope: n/a

"This is a 25-minute exposure of the night sky above Halnaker windmill near Chichester, West Sussex. I wanted to capture the motion of the stars around the celestial pole together with the stillness of the windmill's sails. A low, near-full Moon on the night provided sufficient light to bring out the details of the windmill without glaring out the sky.

"I took this shot, that I have entitled *As the windmills and the heavens turn* using my Canon EOS 30D combined with a Tokina AT-X PRO 12-24 F4 (IF) DXII lens. I took 50 exposures lasting 30 seconds each."

Mark Woodland

Somerset, UK
Telescope: Sky-Watcher Explorer 200P (Newtonian), Sky-Watcher Skymax-102 (Maksutov-Cassegrain), Sky-Watcher Evostar-90 (refractor)

"I'm an Astrophysics student and amateur astronomer. I use a lot of my own equipment for observation, but for imaging I use remote-access telescopes.

"The Eagle nebula (M16) image was captured using **www.telescope.org**, based on the island of Tenerife, with two three-minute exposures and an H-alpha."

Josh Flexen

Worthing, UK
Telescope: William Optics Megrez 72 Doublet APO

"I'm 11 years old and I really like astronomy. My favourite planet is Saturn. I enjoyed looking at Comet PANSTARRS (C/2011 L4) last year and was very pleased that I was able to take this photo. I have also taken a few photographs of the Moon and this is one of my favourites. I borrowed the William Optics Megrez 72 refractor with the Panasonic GH1 camera, but would like to own my own telescope soon."

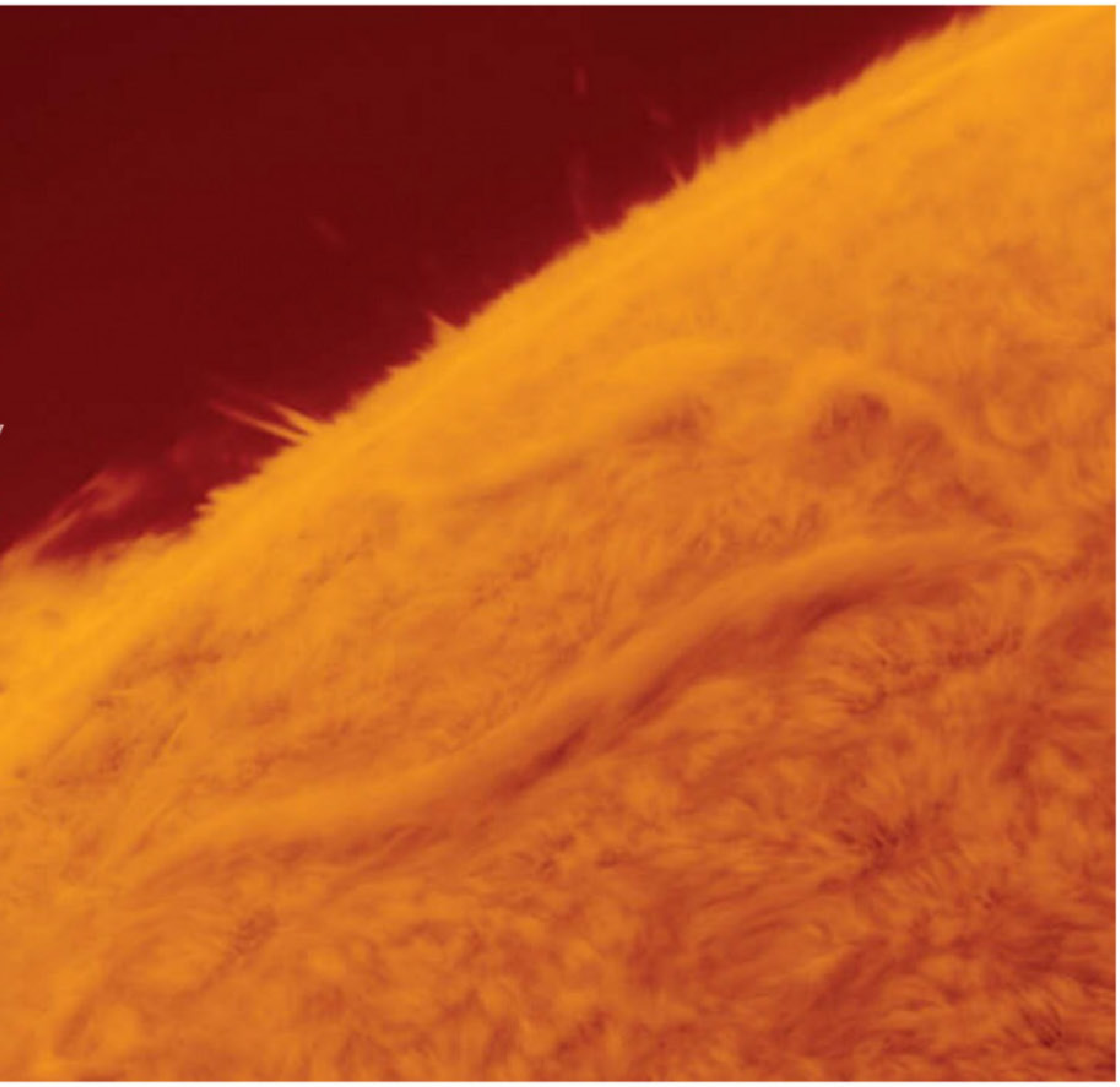
Paolo Porcellana

Castiglione, Italy
Telescope: 150 truss homemade refractor

"When I finally saw through my new telescope after months of waiting, I couldn't believe my eyes – the details and contrast in H-alpha was great and I enjoyed the view, forgetting to capture more images.

"[In this shot], thanks to the brightness of the [Sun], I could image details of the disc surface before splitting the post-processing elaboration to reach a comparable level of luminosity and contrast. I then added colour digitally.

"I have been an amateur astronomer since I was 15 years old. I dedicate my free time to astronomy, in particular photography has always fascinated me and I try to experiment on the image techniques to reach better results."



Send your photos to... @spaceanswers photos@spaceanswers.com

Stargazing stories

Email the story of how you got into astronomy to **photos@spaceanswers.com** for a chance to feature in **All About Space**

Steve Bassett

Location: Worthing, West Sussex, UK
Twitter: @NightSkySteve
Info: Astronomer for four years
Current rig
Telescope: Sky-Watcher 150P
Mount: Sky-Watcher HEQ5 **Other:** Canon 450D, Philips SPC900NC, 15x70 binoculars

"I first had a mild interest in astronomy when I was a child and got my first scope for Christmas aged ten. I remember getting my first view of Saturn through it, which was an incredible thing to see and I can remember the sense of achievement at finding it using a very basic telescope, as well as an alt-azimuth tripod.

"My interest dwindled as I reached my teens and it wasn't until I was 30 that a colleague at work reignited it in a big way. In the four years I have been back in the hobby I have developed a keen interest in astrophotography and public outreach.

"[I've] taken on a role within my local astronomical society – the Worthing Astronomers – helping to organise public observing events in and around the Worthing area.

"A lot of my imaging so far has been from my back garden, which is far from being a dark-sky site, but has yielded some reasonable results. As a society we tend to venture up onto the South Downs north of Worthing, to sites around Findon and High Salvington, which are much better and the Milky Way is an easy target.

"For outreach events we will go somewhere brighter, usually along the promenade in Worthing, since the area gives good planetary and lunar views yet also gives the public a chance to not only look through telescopes but actually see the equipment and us too.

"I was recently invited into one of the local schools to talk to eight and nine year olds about the planets. [I] also tried to convey a sense of scale to the universe in a pictorial form. This was a first for me, but despite the nerves it was a thoroughly enjoyable morning and seeing the enthusiasm that the kids had for the subject was great – I was also impressed by how knowledgeable some were." ■

Steve's top three tips

1. Choose carefully

Get along to a local society meeting or outreach event and take a look at others people's kit. Talk to experienced astronomers before you buy equipment.

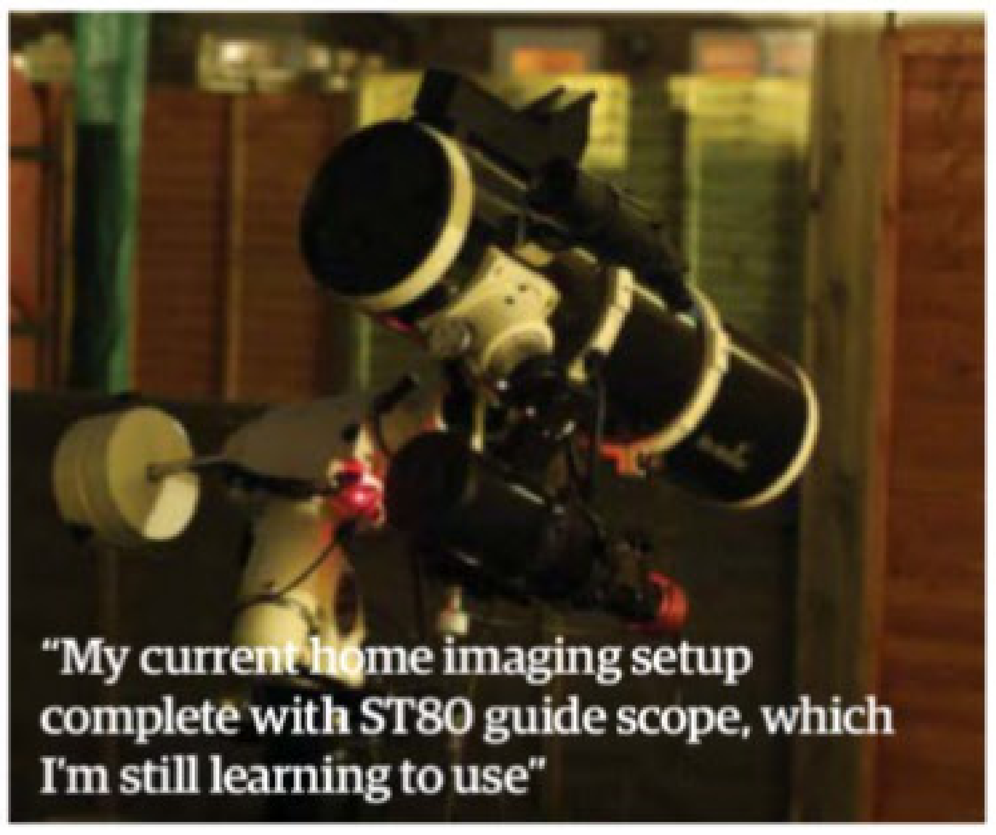
2. Learn the basics

Start simple and build up your equipment, learning from others along the way. Jumping in with both feet from the outset can lead to frustration and info overload.

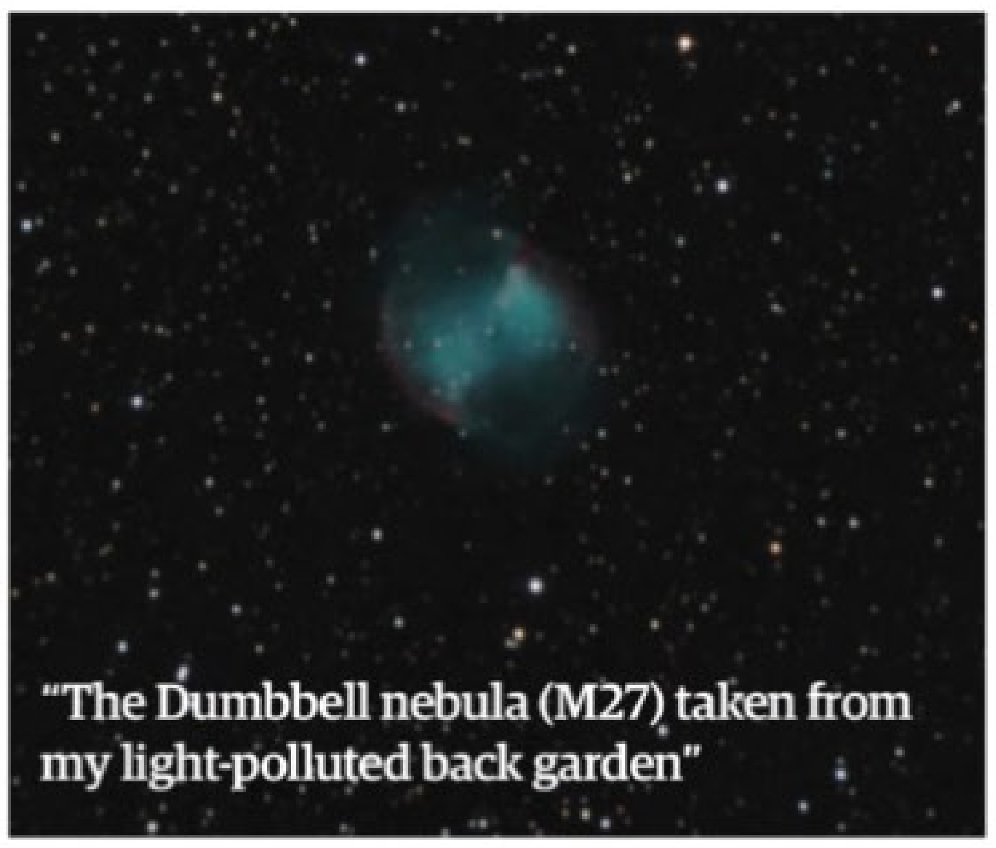
3. Get online

There's a wealth of information and guidance for the beginner on the internet, so be sure to use it either in the form of blogs or online communities.

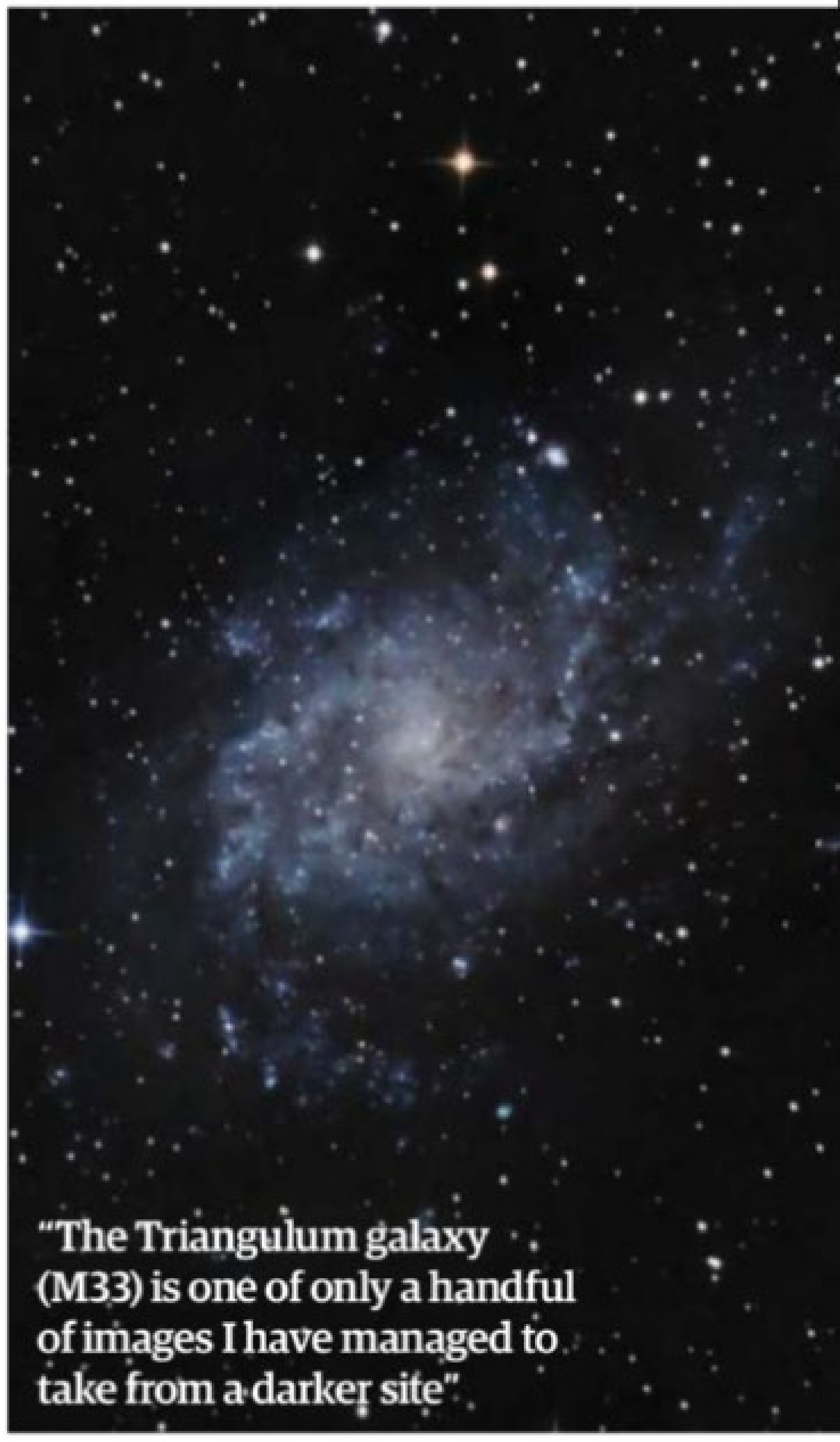
"A young observer very keen to see Jupiter at one of our events. She even got to see some of the gas giant's moons!"



"My current home imaging setup complete with ST80 guide scope, which I'm still learning to use"



"The Dumbbell nebula (M27) taken from my light-polluted back garden"

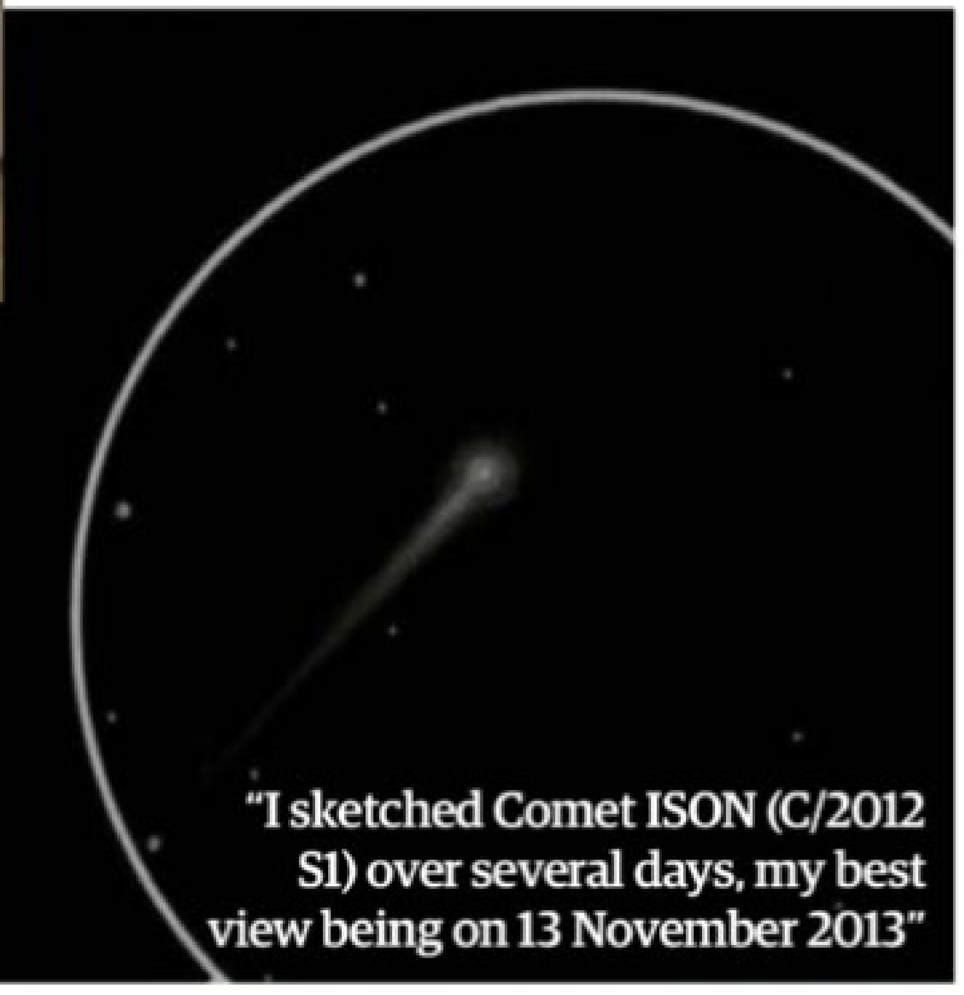


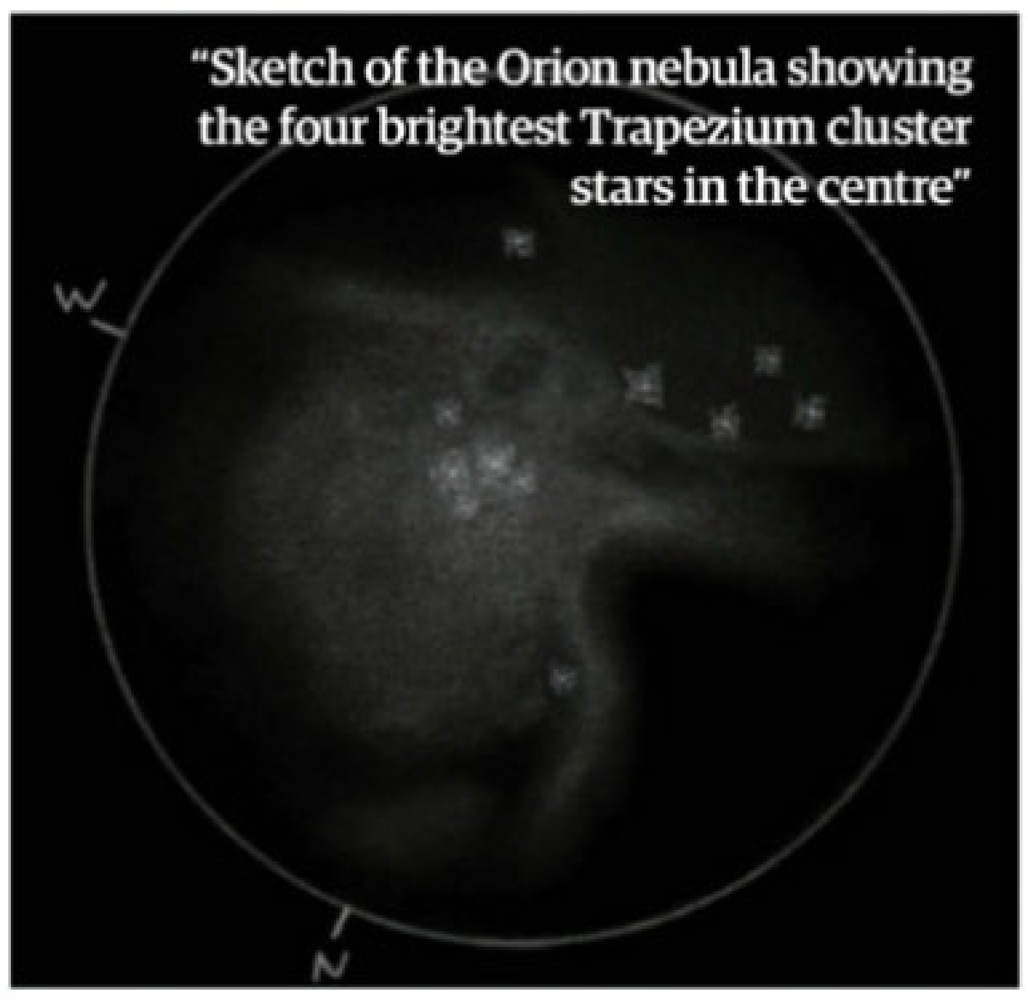
"The Triangulum galaxy (M33) is one of only a handful of images I have managed to take from a darker site"

"A recent outreach event on Worthing seafront with the Worthing Astronomers – these events are getting more and more popular"

Send your stories and photos to... @spaceanswers @ photos@spaceanswers.com

"The dark skies at Kielder Observatory reveal the full glory of the Milky Way"


"I sketched Comet ISON (C/2012 S1) over several days, my best view being on 13 November 2013"



"Sketch of the Orion nebula showing the four brightest Trapezium cluster stars in the centre"

"A red light torch is essential for astronomical observing, as it preserves dark-adapted vision"

"With the *Sky at Night* team at Kielder Observatory filming the Moore Winter Marathon episode"

Steve Brown

Location: Stokesley, North Yorkshire, UK
Twitter: @sjb_astro
Info: Astronomer for three years but I've always had an interest in the subject
Current rig
Telescope: Celestron AstroMaster 130
Mount: Celestron EQ-MD
Other: Miranda 8 x 40 binoculars, Canon 600D DSLR, Celestron lens and filter set.

"I've always had an interest in astronomy but three years ago I decided to develop this further by buying a telescope. After some research I decided that a medium-sized reflector offered the best trade-off between size, portability and price.

The first object I decided to look at was Messier 42, commonly known as the Orion nebula. It was an utterly amazing sight and I knew at once that my purchase had been worth it. No image online or in a book can quite match the experience of seeing M42 through the eyepiece with your own eyes. This experience was repeated as I found other objects, such as the Pleiades and Saturn.

"After that I started observing in my back garden or the nearby North Yorkshire Moors whenever the weather was kind enough to grant me a clear night. I began to want to record my observations, so I started sketching the objects I'd seen. This not only enabled me to keep track of what I'd seen, but it also taught me to be a better observer.

"After about a year of using my telescope I took part in the series of Moore Marathons launched by the late Sir Patrick Moore on the *Sky at Night*...

"As a result of finishing the Moore Winter Marathon, I was invited to take part in the episode presenting the results. This was filmed at Kielder Observatory in Northumberland last year. It was an amazing experience, not only to be on the *Sky at Night* but also to be at Kielder Observatory. Although it was mostly cloudy on the night I was there, I was so impressed with the observatory and location that I have been back several times..." ●

> "No image online or in a book can quite match the experience of seeing M42 through the eyepiece"

Tips for beginners

1. Start simply

You don't need expensive or complex kit to start observing. First learn the constellations using just your eyes or a pair of binoculars and progress from there.

2. Adapt your vision

Take the time to let your eyes adapt to the dark. It takes about 30 minutes for your eyesight to become sensitive enough to see fainter stars and planetary detail.

3. Use dark-sky sites

Try to visit a dark-sky location if you can. The number of stars visible is much greater than from most other locations and a must-have experience for any astronomer!

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Astronomy kit reviews

Must-have products for budding and experienced astronomers alike

1 DVD
First in Space

Cost: £13 (approx. $21)
From: www.amazon.co.uk
Release date: 23 June 2014

This feature film runs for 108 minutes – exactly the length of time it took cosmonaut Yuri Gagarin to blast off into space and return to Earth. Combine this with the impeccable job that Yaroslav Zhalnin (who plays Gagarin) does in capturing the emotion of humanity reaching the final frontier, and you have something that will entertain any space fan.

In the lead-up to the end of the film where Gagarin makes his return to Earth, we're treated to flashbacks of the astronaut's childhood. However, with no continuation of what happened after his flight, where he became a global celebrity, or mention of his death in 1968, we feel important parts of Gagarin's story remain untold here. While this isn't a major flaw of the film, it didn't answer the question of the cosmonaut's life after his achievements depicted. An excellent film overall and very well executed.

2 App
SkySafari 4 Pro

Cost: £28 / $40
From: iTunes / Google Play

We've never been more impressed with an astronomy app than we are with SkySafari 4 Pro, which features 25 million stars from Hubble Guide Star catalogs, over 740,000 galaxies all of the way down to 18th magnitude, as well as 630,000 Solar System objects.

With impressive detail and quality, SkySafari 4 Pro simulates the view from anywhere in the Solar System and beyond as well as into the universe's past or future. Even more impressive is that you get a real-time review of the rotation of the planets.

Its high price will likely put many off, but it's compatible with iPad, iPod Touch and iPhone. Being so useful to all levels of astronomer, we felt that it was worth every penny. There's also the option of purchasing the less-involved SkySafari 4 and SkySafari 4 Plus. Whether you're a serious astronomer or a novice finding your way around the night sky, we couldn't recommend this app enough.

3 Eyepieces
Vixen NPL Plössl

Cost: From £35 / $40
From: www.firstlightoptics.com

We had previously reviewed the Vixen NLV eyepiece series and quickly realised the NPL series was also of exceptional quality – and at just a fraction of the price.

This is because these Plössls are geared more towards the novice astronomer and they don't have as much eye relief as the NLV series – bad news if you wear glasses, since you would need to start at 15mm or above.

Nevertheless, on combining the 8mm and 15mm with a Sky-Watcher Skymax 127, we certainly weren't disappointed – we were quick to favour these eyepieces over the pair that were originally supplied with the telescope. We achieved high contrast, as well as bright and sharp views thanks to fully multi-coated optics and very good colour correction. Planetary detailing, especially of Saturn, was superb and the 50-degree field of view only served to provide more of a stunning observing experience.

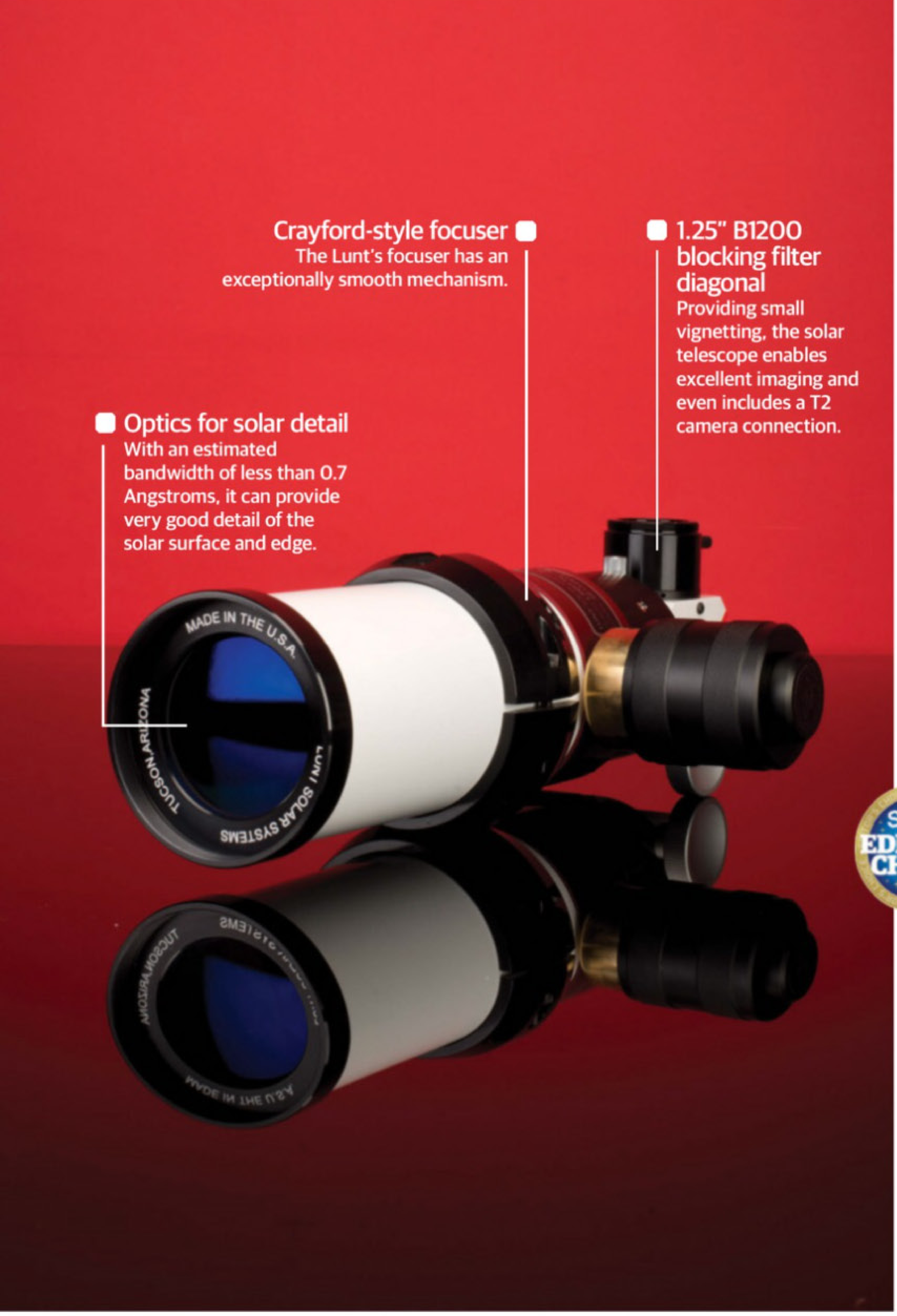
4 Book
Philip's Night Sky Atlas

Cost: £15 (approx. $25)
From: www.amazon.co.uk

We love the accessibility of Robin Scagell's guide to the night sky: this atlas is perfect for individuals new to the hobby but also those more-seasoned stargazers.

Starting with an introduction covering the basics of celestial movement and observational techniques, Scagell's guide provides advice on buying telescopes and binoculars as well as very useful maps of the sky and Moon. Wherever night-sky charts and constellations are drawn, there's a realistic image on the opposite page depicting what you're likely to see during your observations.

Taking the guide on an observing session, the text and charts were easy to follow under the light of a red torch, but when reading the maps with yellow stars on blue backgrounds, the red light was washed out. Nevertheless, this guide is full of info and is useful the year round.



Crayford-style focuser
The Lunt's focuser has an exceptionally smooth mechanism.

1.25" B1200 blocking filter diagonal
Providing small vignetting, the solar telescope enables excellent imaging and even includes a T2 camera connection.

Optics for solar detail
With an estimated bandwidth of less than 0.7 Angstroms, it can provide very good detail of the solar surface and edge.

Lunt 60mm H-alpha Solar Telescope

Combined with a B1200 blocking filter, this H-alpha solar telescope provides excellent sights of our nearest star

The LS60THa doesn't come with additional accessories or a tripod, however, a sturdy case is included

The 60mm-aperture lens is spotless and free of most imperfections

Telescope advice

Cost: £2,129 ($1,596)
From: www.widescreen-centre.co.uk
Type: H-alpha Solar Telescope
Aperture: 60mm
Focal length: 500mm

Nestled inside the sturdy silver case, this solar telescope not only comes well supported, but there's plenty of room to make extra holes in the polystyrene to include further kit. However, we were slightly disappointed that no eyepiece, no Sun-finder and no mounting ring were included with this Lunt.

Nevertheless, it's beautifully constructed, featuring a hefty lens cap, a 1.25" B1200 blocking filter diagonal that promises excellent imaging and a Crayford-style focuser, adding true quality to this piece of equipment. The etalon, which allows the user to fine-tune wavelengths of light, is located halfway down the tube and enabled us to view different features on the Sun's surface at their very best. The 60mm objective lens was spotless and free from imperfections.

Using our own 18mm CEMAX eyepiece, fitting the solar telescope to an alt-azimuth mount, we put the Lunt to work. We were impressed as a bright-orange-red disc popped into view along with a few small solar prominences appearing from the Sun's chromosphere. The sight was stunning, with nothing but sharp views and no vagueness.

Regrettably the tuning ring mechanism was a bit stiff, but this was a small problem when we considered the excellent quality of both the build and optics of this telescope, which actually proved to be better than even the Coronado PST. ●

Rubin, who is most famous for her inferring the existence of dark matter, is seen here measuring spectra

© Science Photo Library

Vera Rubin

Rubin became the first person to prove the existence of dark matter

Vera Rubin was born in Philadelphia, USA in 1928. Her father worked as an electrical engineer, her mother for the Bell Telephone Company and her sister pursued a career as an administrative judge. Rubin was different, however, and was always fascinated by physics and astronomy.

After earning her undergraduate degree at Vassar College, Rubin attempted to enroll at Princeton University where she hoped to continue her dreams of becoming an astronomer. But despite her obvious talent, she was told that "Princeton does not accept women". This extremely unfair policy was not lifted until 1975.

Rubin wasn't put off and applied to Cornell University where she was accepted onto a Master's degree. She studied under highly respected physicists Philip Morrison, Richard Feynman and Hans Bethe. During this time, and unknown to her, she would make one of the first observations of the motions of galaxies. At the time it was suggested that galaxies moved outwards in accordance with the Big Bang theory, but Rubin figured that these structures swirled around some unknown centre. Unfortunately, her suggestion was not well received by the scientific community. Undeterred, she went on to earn her PhD in 1954 from Georgetown University in Washington DC. Her advisor was George Gamow, a theoretical physicist and cosmologist who was an early supporter of the Big Bang theory. Under his supervision, the young Rubin concluded that galaxies were clumped together in clusters, rather than randomly distributed throughout the universe. The idea of galaxy clusters was ludicrous according to the majority of scientists and it wasn't for another two decades that they would be persuaded otherwise.

In 1965, she successfully became the first woman to be granted permission to use the instruments at Palomar Observatory, California. In the same year, Rubin successfully secured a position at the Department of Terrestrial Magnetism at the Carnegie Institution of Washington, where she began work on galaxy clusters - what she found was even more extraordinary than her previous work and would have consequences for our understanding of today's cosmos. When Rubin observed her galaxies, she found that their rotation curves didn't match up to theory. What could the explanation be?

Little did she know, she had found the first indicator for dark matter, an elusive material believed to make up around 25 per cent of the "missing" mass of the universe. Rubin knew that her new findings would be criticised and so, in a bid to avoid it, she decided to slant her research more towards the study of the rotation curves of singular galaxies, rather than the wildly debated galaxy clusters. She began her research with our closest spiral, the Andromeda galaxy.

Luckily, her theory was greeted with open minds as well as prestigious awards. Rubin believed that since galaxies are rotating so fast, the gravity that holds the stars together alone wouldn't be enough to stop the structure from flying apart. There must be something - an unseen mass - holding them together. This binding material would be dark matter.

However, Rubin admitted that she prefers the alternate theory to dark matter, known as MoND (Modified Newtonian Dynamics), a theory that has very little support. "If I could have my pick, I would like to learn that Newton's laws must be modified in order to correctly describe gravitational interactions at large distances," she has said. "That's more appealing than a universe filled with a new kind of sub-nuclear particle." ■

All About Space

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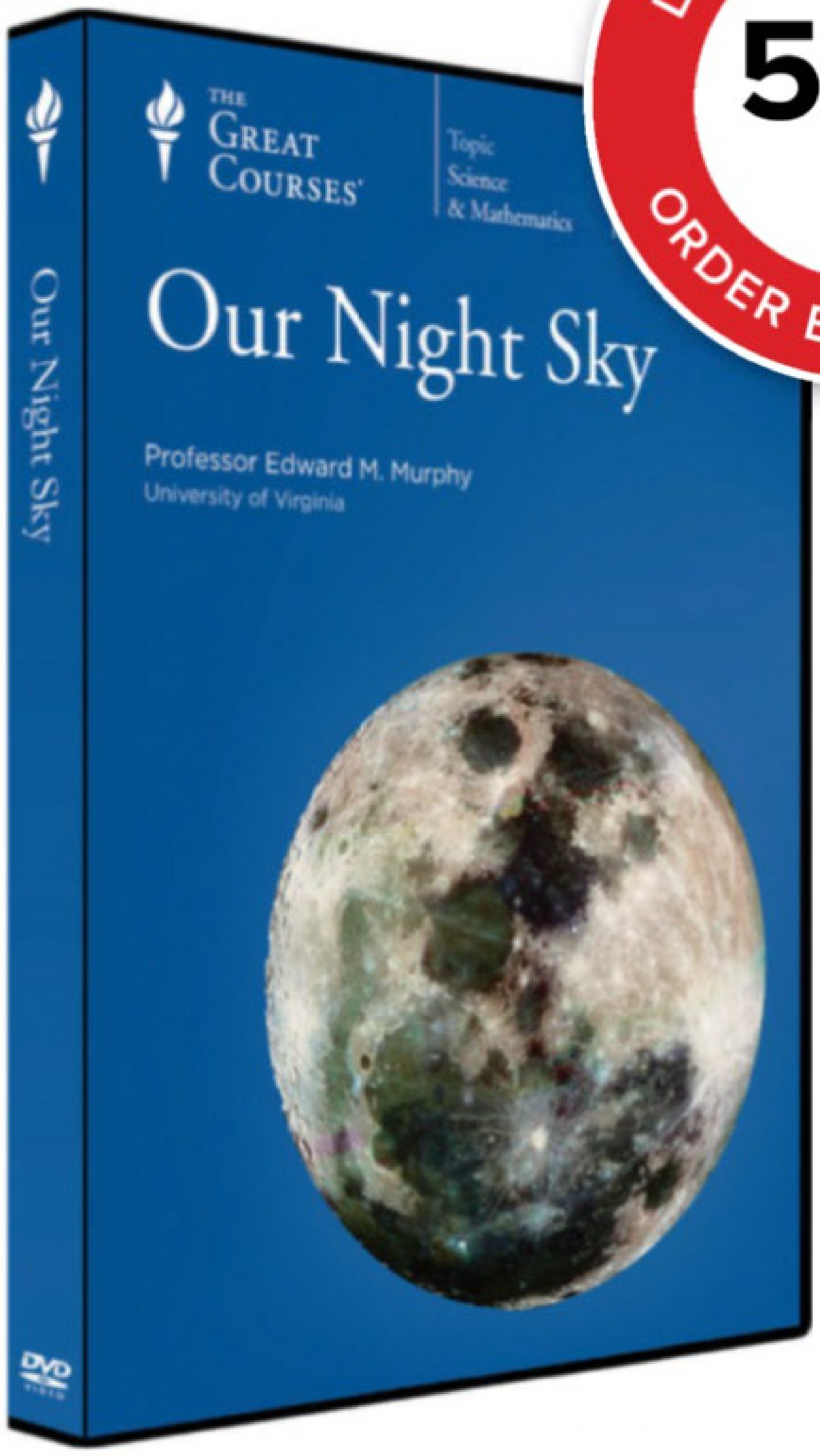

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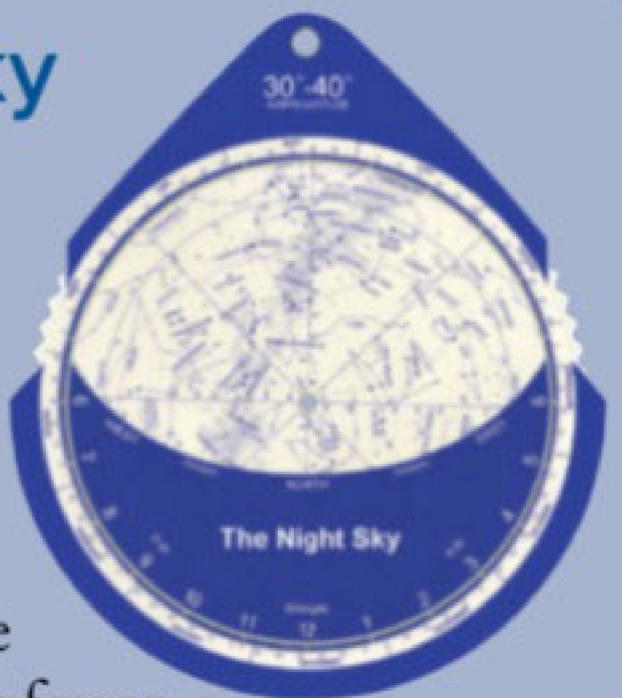

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